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ICRISAT's Objectives

ICRISAT's mandate is to:

1. Serve as a world center for the improvement of grain yield and quality of sorghum, millet, chickpea, pigeonpea, and groundnut and to act as a world repository for the genetic resources of these crops;
2. Develop improved farming systems that will help to increase and stabilize agricultural production through more effective use of natural and human resources in the seasonally dry semi-arid tropics;
3. Identify constraints to agricultural development in the semi-arid tropics and evaluate means of alleviating them through technological and institutional changes; and
4. Assist in the development and transfer of technology to the farmer through cooperation with national and regional research programs, and by sponsoring workshops and conferences, operating training programs, and assisting extension activities.

About This Report

This tenth Annual Report covers the 1983 calendar year.

The Report includes work done at ICRISAT Center near Hyderabad, India, at research stations on the campuses of agricultural universities in different climatic regions of India, and at national and international research facilities in the 10 countries of Africa, Latin America, and West Asia where ICRISAT scientists are posted.

To better reflect the interactive nature of our scientists' work the crop improvement programs are presented as interdisciplinary reports on problem areas. This year for the first time we are reporting work done by our scientists and cooperative programs outside India with the relevant crop or discipline. International Cooperation therefore no longer appears as a separate section. 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. More details of the work reported here are given in individual program publications, available from the research program concerned. Offprints of individual sections of this Annual Report also are available from the programs.

Throughout this Report, the variability of estimates is shown by including standard error (SE); on graphs representing the mean of several observations, the standard error is shown by a line (I). In discussing levels of probability in the text, significance is generally mentioned at the 5% level; where the level differs, it is indicated parenthetically. Levels of probability are shown in Tables by asterisks: * for $P < 0.05$, ** for $P < 0.01$, and *** $P < 0.001$.

Contents

ICRISAT's Five Crops vii
Introduction ix
ICRISAT's Agroclimatic Environment xvi

Genetic Resources Unit 1
Germplasm Distribution 5
Sorghum Germplasm 6
Pearl Millet Germplasm 7
Chickpea Germplasm 8
Pigeonpea Germplasm 9
Groundnut Germplasm 11
Minor Millets Germplasm 11
Looking Ahead 11
Publications 12

Sorghum 13
Physical Stresses 15
Biotic Stresses 20
Biological Nitrogen Fixation 36
Plant Improvement 39
Food Quality 44
International Cooperation 47
Workshops, Conferences and Seminars 60
Looking Ahead 61
Publications 62

Pearl Millet 65
Physical Stresses 67
Biotic Stresses 73
Microbial Associations 85
Plant Improvement 90
International Cooperation 99
Workshops, Conferences, and Seminars 115
Looking Ahead 115
Publications 116

Chickpea 119
Physical Stresses 121
Biotic Stresses 123
Biological Nitrogen Fixation 129
Grain and Food Quality 132
Plant Improvement 134
Cooperative Activities 136
Workshops, Conferences, and Seminars 148
Looking Ahead 149
Publications 149

Pigeonpea 153
Physical Stresses 155
Biotic Stresses 156
Biological Nitrogen Fixation 166
Grain and Food Quality 169
Plant Improvement 171
Cooperative Activities 175
Workshops, Conferences, and Seminars 177
Looking Ahead 179
Publications 179

Groundnut 181
Physical Stresses 183
Biotic Stresses 184
Nitrogen Fixation 205
Plant Improvement 207
International Cooperation 206
Workshops, Conferences, and Seminars 225
Looking Ahead 227
Publications 228

Farming Systems 231
Resource Evaluation 233
On-Station Component Research 235
On-Station Operational Research 265
Evaluation at National Research Centers 272
On-Farm Verification Trials 275
International Cooperation 286
Workshops, Conferences, and Seminars 301
Looking Ahead 303
Publications 305

√

Economics 309

Technology and Policy Assessment 311
Behavioral Studies 321
Resource Management 335
Workshops, Conferences, and Seminars 337
Looking Ahead 339
Publications 340

Training 343

Research Support Activities 347

Plant Quarantine 349
Statistics Unit 352
Computer Services 354
Library and Documentation Services 355
Publications 356

Acronyms and Abbreviations 359

ICRISAT Governing Board 365

ICRISAT Senior Staff 367

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	Sorgo	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

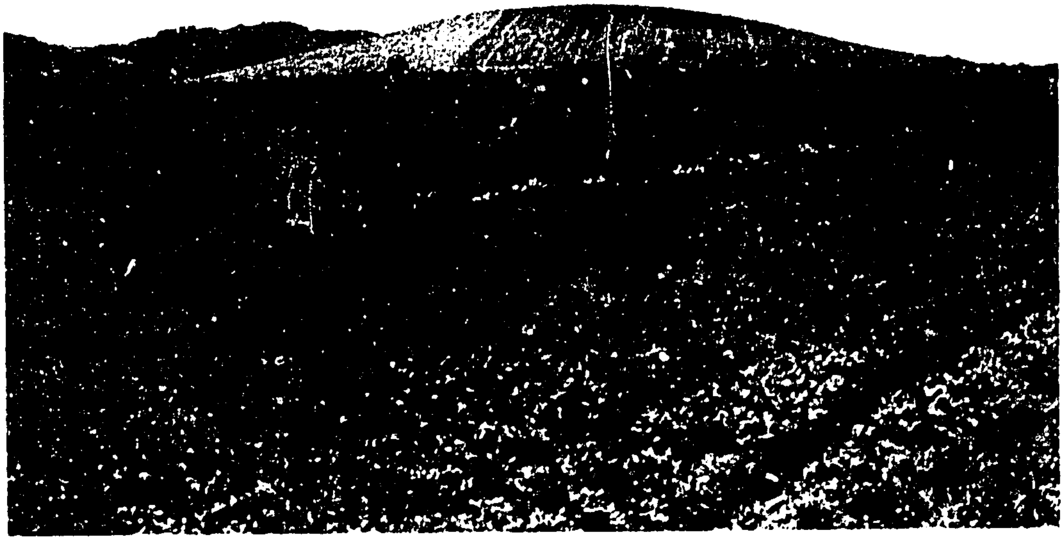
Introduction

In a year when drought was devastating in so much of the world, ICRISAT made progress against it. Lines of our five mandate crops outyielded local cultivars in widespread tests across drought-prone areas of the semi-arid tropics (SAT). In some cases where drought was severe, test lines doubled or tripled the yields of standard varieties.

Under severe drought at Anantapur in southern India this year, six ICRISAT sorghum lines yielded two or three times as much as the best local cultivars. At the same location, with only 220 mm (9 inches) of rain during the crop life, groundnut NC Ac 17090 produced 2530 kg/ha, compared with 1100 kg/ha by Robut 33-1, the recommended cultivar.

In Africa, we moved forward in developing an interdisciplinary team and research facilities at the ICRISAT Sahelian Center in Niger, establishing a base in a chronically drought-prone area of the world. The major work there is on pearl millet, a staple food of the region, and with our sister institutes, IITA and ILCA, on cowpeas and livestock in farming systems of the region.

Groundnut lines doing well at Anantapur, southern India, where ICRISAT tests groundnuts, millets, and sorghums under drought conditions.



Ergot disease damages pearl millet badly. Through studying such diseases and the mechanisms by which plants resist them, ICRISAT has become a repository of plant materials with multiple resistance to diseases and pests in most of its crops.

We also made progress this year in controlling the other major yield reducers of our mandate crops: diseases and pests. We are producing in most of our crops breeding lines that are resistant not just to one but to several diseases, and to insect attack as well. These lines are turned over to breeders in national programs throughout the SAT to use locally in producing adapted varieties.

Over the years ICRISAT scientists have identified or developed more than 600 sorghum lines with useful resistances. We are now combining several traits in lines that can grow well in farmers' fields. For example, of 83 sorghum lines identified for shoot fly resistance in 1983 tests, 10 had excellent yield (60% or more above the control variety); and 4 of them had multiple resistance to diseases and other insect pests.

ICRISAT has become a major source of materials with high resistance to specific diseases of pearl millet, and particularly with multiple resistances. All sources of resistance to ergot, smut, and rust, which we have identified or developed, have resistance to downy mildew because they are all screened in our downy mildew nursery.

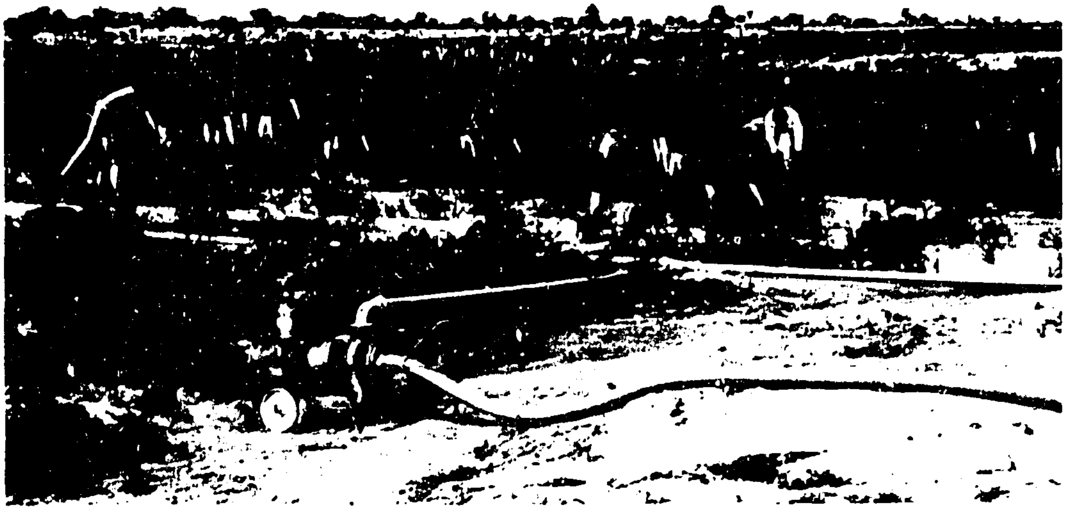
The three most serious diseases of groundnut worldwide are rust, early leaf spot, and late leaf spot. We have no breeding line yet with resistance to all three, but we have eight lines with high resistance to rust and late leaf spot. And we have identified three lines with resistance to rust and early leaf spot.

Our success in breeding for multiple disease resistance in chickpea is also encouraging. We have 18 lines resistant to wilt and black root rot; 17 to wilt and dry root rot; 2 to wilt, dry root rot, and black rot; and several that resist two wilts, molds, or blights.

Ascochyta blight, a major destroyer of chickpea crops, has been epidemic in many of the 25 countries where it occurs in Africa, Asia, Europe, the Americas, and Australia. ICRISAT and ICARDA, working together, have developed a variety released in Syria in 1982, ILC 482, which resists the blight.

Pigeonpea demonstrated great potential this year for raising the SAT farmer's standard of living. A noteworthy development in 1983 was the 5500 kg/ha from three harvests of the early-maturing pigeonpea, ICPL 87, compared with 2500 to 3000 kg/ha from two harvests of the medium-maturing pigeonpeas in peninsular India. The three early-maturing crops require 220 days, compared with 240 days for the two medium-maturing crops.

Pearl millet trials in progress at the ICRISAT Sahelian Center, where the base for crop research has now been established.



The technology developed by ICRISAT for double cropping deep black soils with assured rainfall (750-1250 mm per year) continued to do well in on-farm verification in India. Testing of this technology was extended by state departments of agriculture to 22 locations from 8 the previous year in the four Indian states: Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra.

Excessive runoff and soil erosion arising from large rainstorms are a chronic problem in the SAT. So is waterlogging, which is caused by poor infiltration. To better understand those problems and find practical solutions, ICRISAT scientists this year built a rainfall simulator that will let us study rainfalls of various intensities, and also modified the contour bunding system practiced by farmers. The refined contour bund system increased yields 21% in 1983.

Training is a vital element in the transfer of technology. Scientists and technicians came from 26 countries for in-service training at ICRISAT during 1983. Fourteen in post-Ph.D. programs worked with ICRISAT scientists, and students from 15 countries did research for Ph.D. and M.S. degrees. Additionally Latin Americans took ICRISAT training in Mexico, and West African

Farmer and grandson examine pheromone trap at Begumganj, Madhya Pradesh, one of 22 locations in India where ICRISAT's technology for deep black soils with assured rainfall did well in on-farm tests.

Above, in-service fellow from Uganda studies sorghum disease with ICRISAT pathologist. Scientists and technicians from 26 countries received training at ICRISAT Center during 1983. Below, a group of farmers show interest in a groundnut experiment. Some 600 farmers braved the rain to visit ICRISAT Center on Farmers' Day.

students did thesis-related work supervised by ICRISAT staff in Mali, Niger, Senegal, and Upper Volta.

Another means of transferring technology is through conferences, workshops, symposia, and seminars. During 1983, we sponsored or cosponsored 12 such meetings. Four related to farming systems work in transferring knowledge to the ultimate user—the farmer. Four workshops by economists dealt with technology options for dryland agriculture, farmers' participation in development and evaluation of technologies (at Ouagadougou, Upper Volta), village-level studies, and an international workshop on agricultural markets in the semi-arid tropics.

Other international conferences were concerned with research needs and strategies for control of sorghum root and stalk rot diseases, pest management in pulses, and the cytogenetics of *Arachis*.

During the year we had 9000 visitors from many parts of the SAT and from our donor countries. They included Her Majesty Queen Elizabeth II and Prince Philip; Mrs. Eegje Schoo, Minister of Development Cooperation for the Netherlands; and members of the Japanese Diet. We also were visited by President Forbes Burnham of Guyana, government administrators and policy-

Legume scientists from Asia visit a pigeonpea field during a meeting at ICRISAT Center to make plans for improved production of groundnuts, chickpeas, and pigeonpeas. ICRISAT sponsored or cosponsored 12 major conferences during the year.

Queen Elizabeth II and Prince Philip hear ICRISAT scientist explain functions of the bullock-drawn wheeled tool carrier on their visit to ICRISAT Center.

makers, and scientists from around the world who came to see ICRISAT's work. Among other visitors were 600 farmers from three states of India for our annual Farmers' Day.

As the year ended, we looked forward to beginning an ICRISAT-USAID program to improve sorghum and pearl millet production in the drought-prone countries of the Southern African Development Coordination Conference (SADCC).

In a meeting at ICRISAT Center in December, we made plans for a major regional grain legumes program in South and Southeast Asia. The participants represented research organizations in India, Indonesia, Nepal, Pakistan, the Philippines, and Thailand, and several international organizations interested in agricultural development in Asia. They focused on the need to improve production of groundnuts, chickpeas, and pigeonpeas.

As we begin our 12th year, we feel ICRISAT is well on the way to meeting its mandate to increase food production in the semi-arid tropics of the world.

L.D. Swindale
Director General

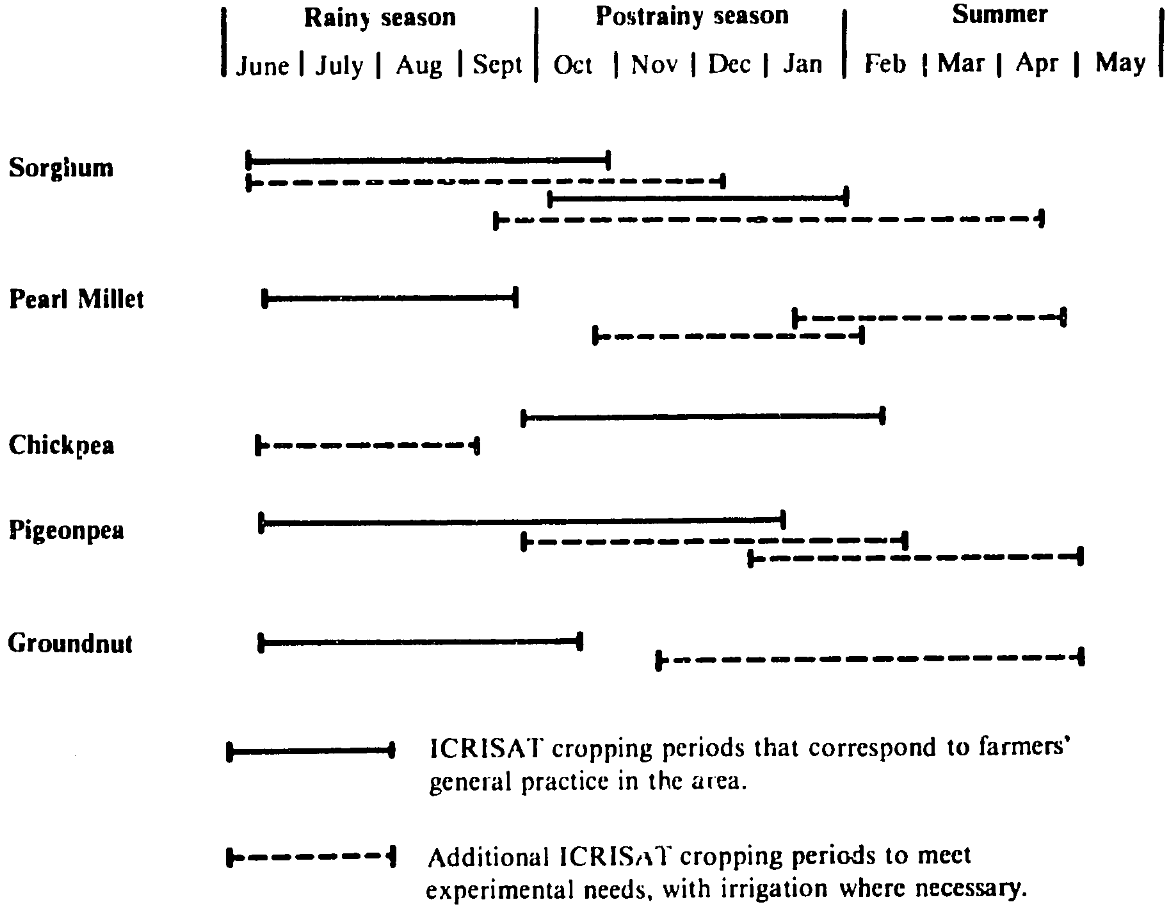
ICRISAT's Agroclimatic Environment

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 from ICRISAT scientists posted at cooperative stations in India, in eight African countries, and in Mexico and Syria. As background to our research reports, this section presents a brief description of the environments where most of our research in India is conducted and includes data for the ICRISAT Sahelian Center for comparison. Pertinent data for weather outside India are given in the program reports.

ICRISAT Center

The Institute is located at 18°N, 78°E on 1394 hectares near Patancheru village, Andhra Pradesh, 25 km northwest of Hyderabad on the

ICRISAT Center's Cropping Schedule



ICRISAT cropping periods that correspond to farmers' general practice in the area.

Additional ICRISAT cropping periods to meet experimental needs, with irrigation where necessary.

Bombay highway. The experimental farm extending over 1394 hectares 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 a high water-holding capacity. The availability of both soil types provides an opportunity to conduct experimental work on our five mandate crops under conditions representative of may SAT areas.

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 those four months, in which rainfed crops are raised. The postrainy winter season (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, dry summer season is from February until rains begin again in June. Any crop grown then 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 grown under irrigation. Pigeonpea is generally sown at the beginning of the rainy season and continues growing through the postrainy season; to provide additional genetic material for our breeding program, we plant an irrigated crop of early-maturing types in December. As in normal farming practice, two crops a year of sorghum can be grown at the Center, one during the rainy season; 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, the crops are often grown in various combinations and sequences, which we are working to improve.

Cooperative Research Stations in India

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

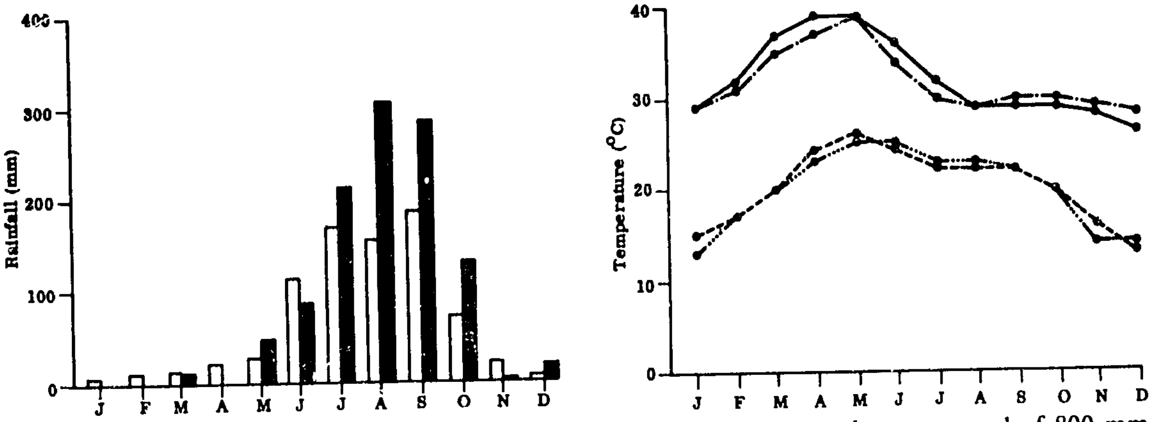
Crops. Our oldest cooperative station at Hissar is also the largest, with 40 ha. Cooperative work started there in 1975 to test chickpea and pearl millet in the climatic conditions where they are mostly grown—a belt that stretches across north India (and West Asia for chickpea,and the Sahelian zone of 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. The need to extend 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 an effective screening site in the region where most of India's late-maturing pigeonpea crop is grown, and also provides an alternative site for selecting chickpea. Anantapur, a drought prone area, has been used since 1980 during the rainy season to screen pearl millet, sorghum, and groundnut for drought.

The Weather

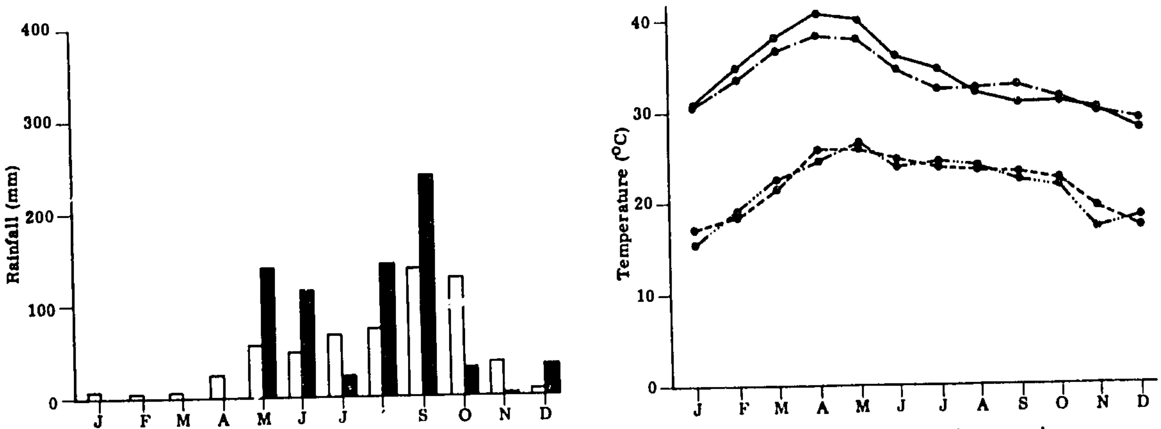
In the following figures we present rainfall and temperature data for the main locations of our research.

Normal rainfall ☐■ 1983 rainfall

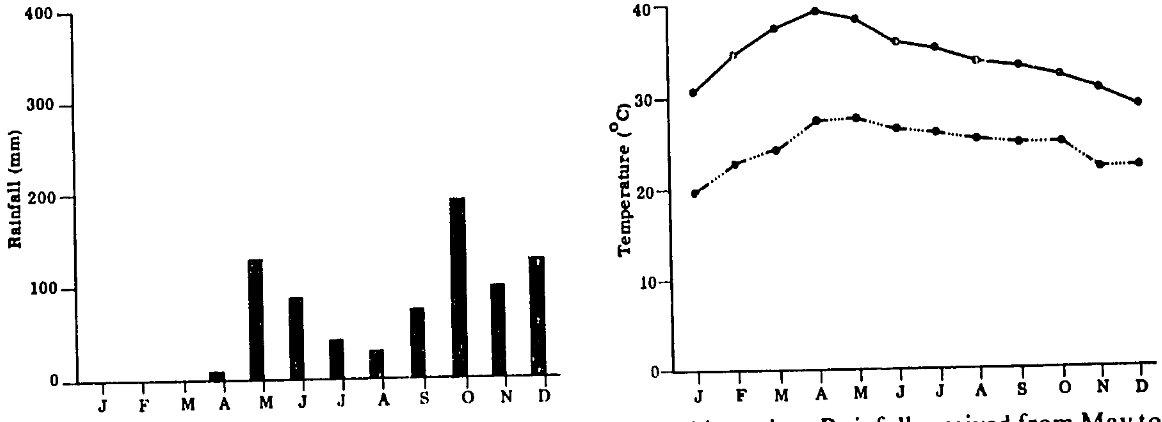
●—·—● Normal max temp
●——● 1983 max temp
●----● Normal min temp
●·····● 1983 min temp



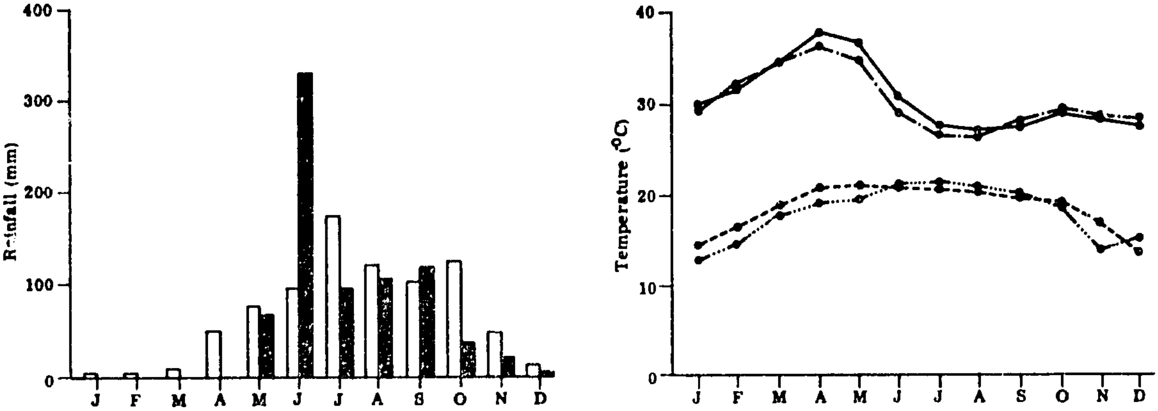
ICRISAT Center. The annual rainfall in 1983 was 1099 mm compared to a normal of 800 mm. Rainfall received during June was 24% less than normal; however, the rainy season total (June to October) was 1022 mm.



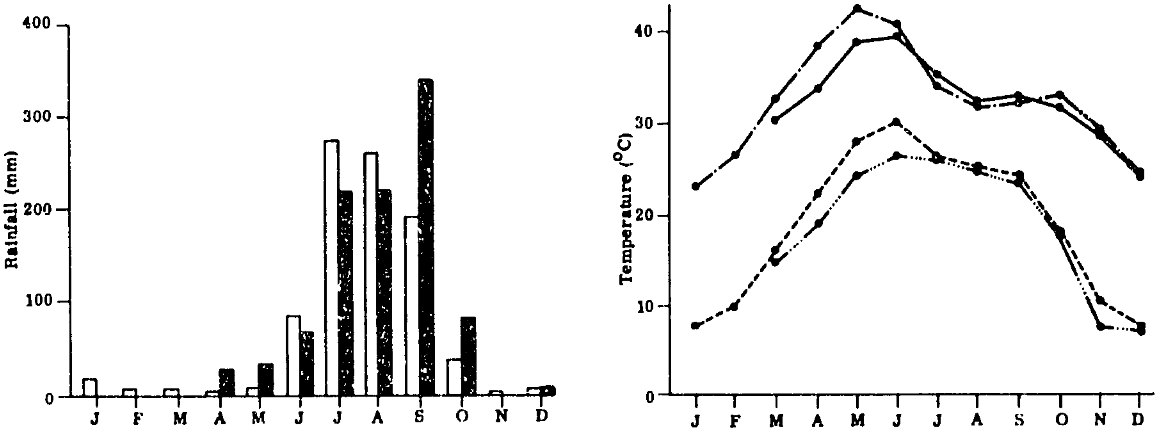
Anantapur. Of the 590 mm mean annual rainfall, over 80% is spread over a long rainy season extending from May to October. Rainfall in the 1983 rainy season was 691 mm, 35% above normal.



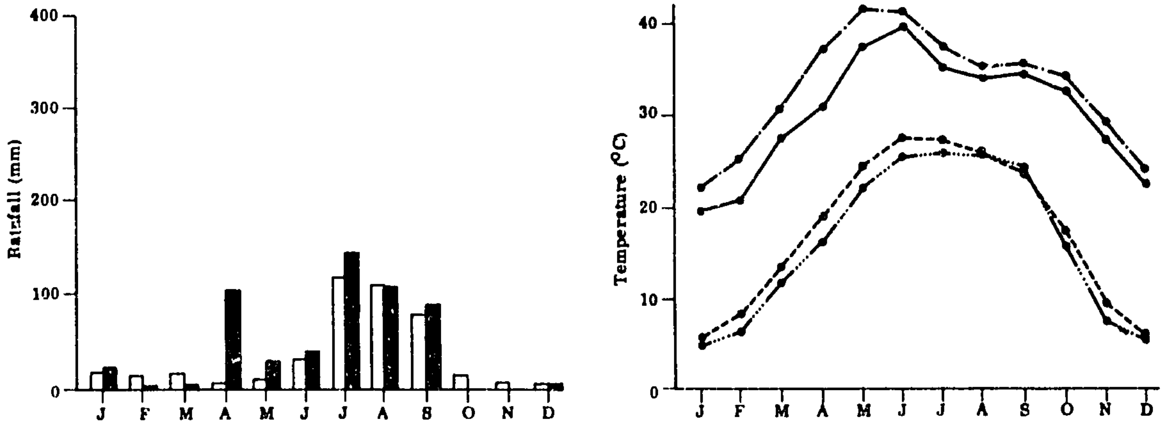
Bhavanisagar. Normal rainfall data are not available for this station. Rainfall received from May to December 1983 was 773 mm.



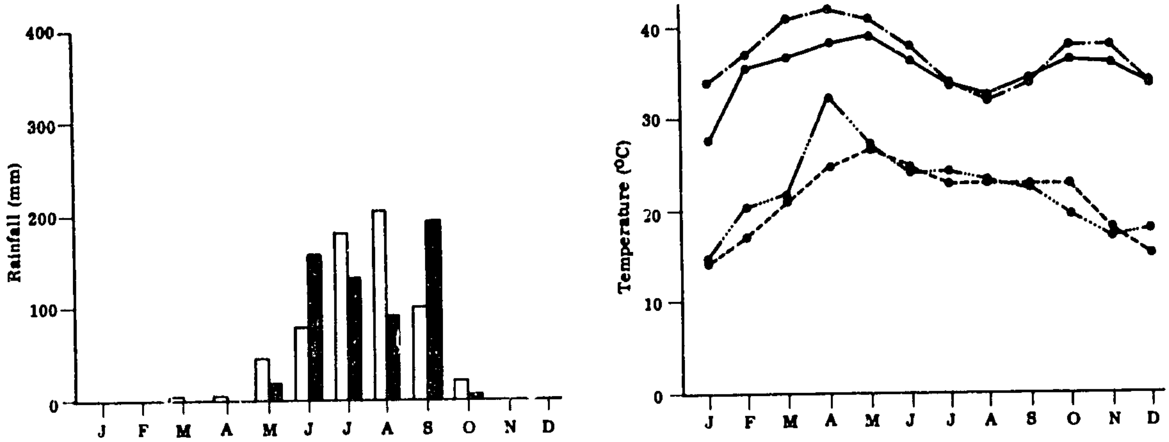
Dharwar. Rainfall received from May to October 1983 was 756 mm, 8% above the normal 697 mm for this period.



Gwalior. Rainfall received during the 1983 rainy season (June to October) was 916 mm, 10% above the normal 843 mm.



Hissar. Rainfall received from June to September was 391 mm, near the normal 351 mm for the season. The total annual rainfall, 456 mm, was also near the normal 447 mm.



ICRISAT Sahelian Center. Normal rainfall from June to October at Niamey is 588 mm in 1983 it was 581 mm.

GENETIC RESOURCES UNIT

Contents

Germplasm Distribution 5

Sorghum Germplasm 6

Pearl Millet Germplasm 7

Chickpea Germplasm 8

Pigeonpea Germplasm 9

Groundnut Germplasm 11

Minor Millets Germplasm 11

Looking Ahead 11

Publications 12

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-2-

GENETIC RESOURCES UNIT

The Genetic Resources Unit is custodian of ICRISAT's germplasm collections. As an extensive base for present and future crop improvement, the collections continue to be tapped by crop improvement scientists working in ICRISAT and around the world.

Crop improvement tends to narrow the genetic base of crop plants. New cultivars that are successful, replace old landraces, evolved over centuries of domestication and selection. The replacement is vital in the interests of higher production and better nutrition, but the widely diverse germplasm from farmers' fields must be preserved for use by present and future generations of mankind.

Calamities, natural and otherwise, and overpopulation threaten the genetic diversity of crop plants by destroying their habitat. Droughts and habitat destruction threaten populations of domesticated plants' wild relatives, especially the less agressive types, which include most, if not all, relatives of pulses and groundnuts. The long awaited breakthrough to improved, high yielding cultivars in pulses, will trigger genetic erosion of their old landraces.

Hybrid and improved open-pollinated cultivars of sorghum and millet have spread and made an impact on their landraces, which are not yet collected from all areas. As these crops are major food and cash crops of small farmers in the SAT, the need to collect, maintain, evaluate, preserve, and distribute their germplasm becomes increasingly important. ICRISAT's Genetic Resources Unit is a partner in the worldwide network of genetic resources centers to accomplish conservation of genetic resources.

By the end of 1983, a total of 76 632 accessions had been entered in the gene bank. Table 1 shows progress in the last 5 years, and Table 2 additions in 1983. Important collections in 1983, which reduced geographical gaps in our collection, came from northern Cameroon, parts of India, Malawi, Nigeria, Sierra Leone, and southern Sudan. Our collection efforts secured 1567 new accessions during 1983. And hundreds of samples, not all of which have been released or incorporated in the collection, were sent by donors.

Our priority collection areas do not differ substantially from a year ago, except that countries mentioned above are now well represented. Future collection efforts will be directed toward:

Sorghum : Angola, Central African Republic, Chad, Ghana, Ivory Coast, Lesotho, Morocco, Mozambique, Swaziland, Uganda, Yemen AR, Yemen PDR, southern Turkey, Nepal, parts of India, China.

Pearl millet : Angola, Chad, Egypt, Ethiopia, Ghana, Mauritania, Upper Volta, parts of India, Pakistan.

Chickpea : Turkey, Burma, northeastern India, Pakistan, northern and southern Ethiopia, Tanzania.

Pigeonpea : Uganda, Zaire, Burma, southeastern China, parts of India, Indonesia, Australia, Caribbean Islands, southern Philippines.

Groundnut : East, West, and Central Africa, Burma, China, Indonesia, Thailand, South America.

Not included are parts of primary areas of diversity that still remain inaccessible.

Our new physical facilities help us provide rapid handling of seed samples for supply, evaluation, and viability monitoring. The medium-term modules are operational, and the long-term storage modules, financed by the Asian Development Bank, have arrived and will be erected in 1984.

All germplasm is now stored at 4 to 5°C and 30 to 40% relative humidity. Germination tests

Table 1. ICRISAT mandate crops' germplasm progress.

	Sorghum		Pearl Millet		Chickpea		Pigeonpea		Groundnut	
	1978	1983	1978	1983	1978	1983	1978	1983	1978	1983
ACCESSIONS										
Assembled	15304	22898	6796	16022	11228	12987	6479	9648	6511	10565
Evaluated	15135	20355	5962	15388	9500	12000	5958	9099	6394	10248
Documented[1]	7215	11351	340	7379	7200	12967	5801	8718	-	8000[3]
Distributed										
-in ICRISAT	34938	135850	1482	13942	25599	72682	9905	40840	862	24288
-in India	8864	23036	7945	14112	4065	19383	5765	14057	1640	12352
-abroad	8320	56595	5407	11541	11786	33151	3482	6171	1626	7893
Wild species (acces.)	5(118)	21(345)	11(17)	20(57)	14(77)	14(135)	25(62)	46(228)	13(33)	22(181)
Countries represented	54	79	15	30	35	40	30	35	50	84
Collection missions	4	16	3	13	9	18	18	40	2	12
GENETIC STOCKS										
Disease resistant[2]	64	133	-	27	-	277	-	628	-	61
Insect resistant[2]	30	115	-	-	-	22	-	27	-	73
Drought resistant[2]	133	246	-	7	-	10	-	-	-	12
Striga low stimulant[2]	236	645	-	-	-	-	-	-	-	-
Glossy	-	501	-	8	-	-	-	-	-	-
Popping	-	36	-	-	-	-	-	-	-	-
Sweet stalk	-	41	-	4	-	-	-	-	-	-
Male-sterile lines	93	120	9	17	-	-	2	4	-	-
Dwarfs	9	11	1	14	-	-	-	5	-	2
Chlorophyll mutants	-	-	-	11	1	3	-	-	1	2
Two pods per axil	-	-	-	-	71	105	-	-	-	-
Other characters	131	187	-	7	16	20	9	18	-	83

1. Entered in computer.
2. Promising lines.
3. Tabulated.

Specimens of cultivated and wild relatives of our mandate crops are preserved in our reference herbarium.

of sorghum seeds conserved since 1975, first at about 20°C and 60% relative humidity, but since 1980 in the present stores, showed that nearly all genotypes still had at least 90% germination. The few that germinated below 85% already have been rejuvenated.

We also keep a working herbarium of specimens for research and reference purposes.

Chickpea and pigeonpea were tested at Hissar, India, as was sorghum in Cameroon. The entire Cameroon sorghum collection, which was evaluated at Maroua, Cameroon, was transferred back to Cameroon from ICRISAT. At Hissar the 1982-83 chickpea evaluation again

Table 2. Additions to ICRISAT germplasm collection in 1983.

Origin	Sorghum	Pearl Millet	Chickpea	Pigeonpea	Groundnut
AFRICA					
Benin		23			
Ethiopia			392		
Ghana	84	7		-	-
Kenya	-	22	-	-	
Mali	-	166	-	-	-
Nigeria	197	14	-	-	-
Rwanda			-	-	2
Senegal		50	-	-	-
Sudan	70	240	-	-	-
Tanzania	-	-	-	-	42
Togo	-	17	-	-	-
Zambia	81	4	-		
Zimbabwe		35	-	-	42
ASIA					
Afghanistan			1	-	-
India		42	80	36	-
Iran		-	3	-	-
Japan		-	-	-	16
Turkey		-	1	-	-
EUROPE					
Netherlands	-	-	-	-	4
Spain		-	1	-	-
USSR	-	-	6	-	-
THE AMERICAS					
Surinam	-	-	-	-	1
USA		14	-	-	240
Unknown		-	1	-	7
Total in 1983	432	634	485	36	354
Total to date	22898	16022	12987	9648	10565

Additions to minor millets collection.

Species	Accessions
Eleusine coracana (finger millet)	91
Setaria italica (foxtail millet)	50
Panicum miliaceum (proso millet)	2
Panicum sumatrense (little millet)	41
Echinochloa crusgalli (barnyard millet)	31
Paspalum scrobiculatum (kodo millet)	2
Total in 1983	217
Total holdings	4512

succumbed to leaf diseases and salinity. Early pigeonpea genotypes evaluated at Hissar matured much later than at ICRISAT Center.

Table 3 sho' 'he number of germplasm samples sent to scientists in and outside India during 1983 and many were again shared with Institute scientists for further screenings.

Documentation was further advanced with cereal evaluations computerized up to IS 16 676 (sorghum) and IP 10 000 (pearl millet). The 1981-82 pulses data are processed up to ICC 12 336 (chickpea) and ICP 10 954 (pigeonpea). Groundnut data are now being computerized. Data or sets of genotypes falling within certain prescribed ranges are regularly retrieved to fulfil demands.

Germplasm Distribution

As in previous years, thousands of germplasm samples were supplied to crop improvement scientists in 1983, as shown in Table 3, which does not include 38 000 samples used at ICRISAT for screening and research. When we recently attempted to monitor (by questionnaire) use of our germplasm by crop improvement scientists throughout the world, respondents were enthusiastic about using our germplasm lines in their crop improvement programs.

Requests for seed samples should be directed to ICRISAT's Genetic Resources Unit, with import permits attached if needed for shipments abroad.

Using the descriptors and descriptor states jointly published by the International Board for Plant Genetic Resources (IBPGR) and ICRISAT facilitates selection of samples with specific characteristics.

We are anxious to receive seed samples from areas not explored, and material with useful or distinct traits. Scientists who want to add samples to the world collection should send them, with a phytosanitary certificate, to the Project Director, Central Plant Protection and Training Institute, Ministry of Agriculture, Govt. of India, Rajendranagar, Hyderabad 500 030,

Table 3. Germplasm samples[1] distributed in 1983.

Crop	To India	To other countries	Total samples	No. of other countries[2]
Sorghum	3415	18080	21495	29
Pearl Millet	580	514	1094	16
Chickpea	4200	6348	10548	14
Pigeonpea	1597	591	2188	17
Groundnut	1210	1439	2649	21
Minor Millets	212	540	752	10

1. Figures do not include more than 38000 samples of germplasm shared with ICRISAT scientists.
2. Germplasm from most of these countries has been provided to ICRISAT.

Andhra Pradesh, India, at the same time, send separately particulars of your samples, time and mode of dispatch to ICRISAT's Genetic Resources Unit. Green and white labels to accompany samples may be obtained in advance from ICRISAT.

Sorghum Germplasm

This year, 432 new accessions were rejuvenated and added to the sorghum gene bank, raising the total to 22898. The new accessions were assembled from Ghana (84), northern Nigeria (197), Zambia (81), and from Sudan (70) by correspondence.

The farmer's grain storage cots, like this one in Cameroon are often a good source of germplasm from freshly harvested crops.

Collection expeditions were organized in Cameroon, Sierra Leone, and the Juba area of southern Sudan. Sorghum landrace cultivars collected from Sierra Leone belong to the species *Sorghum margaritiferum* as described by Snowden. The grain is small, corneous, well exposed between gaping involute glumes with characteristic twisting. These sorghums are mainly used for food and cooked like rice. They are adapted to high rainfall (about 2500 mm), tropical climate, and resist weathering. The collecting expedition in Sierra Leone was accompanied and assisted by a former ICRISAT trainee (see section cover photograph).

A total of 2478 accessions from Benin (193), Burundi (96), Ethiopia (217), Kenya (111), Malawi (7), Mali (777), Rwanda (167), South Africa (122), Togo (260), Yemen Arab Republic (451), and others via UK (77), were grown in the PEQIA (Postentry Quarantine Isolation Area) for inspection and release. Pending clearance by the Government of India National Plant Quarantine Service are 252 accessions from: Cameroon (100), Sierra Leone (125), and Sudan (27).

To meet the increasing requests for seed, we rejuvenated 4828 accessions during the postrainy season by selfing. All are now conserved in medium-term cold storage. During postrainy and rainy seasons, 972 newly assembled accessions were characterized and evaluated, using ICRISAT/IBPGR sorghum descriptors, at

ICRISAT. Up to 20 355 accessions have been evaluated, and passport and evaluation data up to IS 16 676 have been computerized and can be retrieved on request.

Collaborating with ICRISAT Sorghum Improvement Program, we screened 14222 accessions of sorghum germplasm for insect, disease, and drought resistances, cold tolerance, and grain quality.

A basic collection of about 1200 accessions was selected from the world collection by taxonomical and geographical stratification, based on their ecological adaptation at ICRISAT Center. Many sorghum scientists in India are already using the material.

As part of regional germplasm evaluations at or close to the place collected, 1827 accessions of the Cameroon collection from the ICRISAT gene bank were transferred to, and grown at, the Institute of Agronomic Research, Maroua, North Cameroon, and evaluated in a collaborative project. The collection was classified up to subrace level, and a basic collection developed for use in Cameroon crop improvement programs. The data have been processed and computerized at ICRISAT Center.

To introgress useful genes from wild relatives of sorghum into adapted cultivars, we crossed E 35-1 (an agronomically elite Zera-zera) and *Sorghum propinquum* (a geographically isolated wild relative of sorghum). F_1's were intermediate with freely shattering seeds. F_2 populations will be grown and selected in 1984 for desirable segregants, mainly those that resist shoot fly.

Our conversion program was continued to promote flow of tropical germplasm into breeding programs. F_3 and F_4 backcross populations grown at ICRISAT Center in 1983 produced promising segregants; nearly 997 selections were made by breeders/and trainees. Another 253 lines closely resembling Zera-zera landraces with variable maturity and height backgrounds were selected to be included as conversion lines and bulks. Additionally, 80 early dwarfs were selected to identify a suitable 4-gene dwarf to use as a nonrecurrent parent in the conversion program.

Pearl Millet Germplasm

In collaboration with the Institute for Agricultural Research (IAR), Ahmadu Bello University, we sent an expedition to northern Nigeria where 388 samples of cultivated pearl millet and 2 of its wild relatives, *Pennisetum polystachyon* and *Cenchrus* sp, were collected. From Sierra Leone, we collected 59 samples of cultivated and wild relatives, and 3 wild and 4 cultivated samples from Sudan. In Punjab, India, 204 samples were obtained in a joint collection with the Punjab Agricultural University at Ludhiana.

In the PEQIA, 1141 samples were sown, of which 592 were released. The 592 were imported from Benin (23), Ghana (7), Kenya (22), Mali (166), Nigeria (14), Senegal (50), Sudan (24), Togo (17), Zambia (4), Zimbabwe (35), and the USA (14). We added 42 accessions from Rajasthan and the Eastern Ghats, India. During the

Collecting pearl millet germplasm in Punjab, India, in cooperation with the Punjab Agricultural University; 204 samples were added to the ICRISAT gene bank.

postrainy season, we grew 3468 accessions for rejuvenation. New accessions not evaluated earlier were sown in June, so evaluation data from 648 accessions were added to our data files.

Natural-occurring dwarf variants of pearl millet were isolated during rejuvenation and evaluation. Segregation of the heterozygous lines indicated that dwarfness is controlled by a single recessive gene, except in IP 8210 and IP 8214; when 14 dwarfs were crossed to d_2, the extensively used dwarfing gene, nine of the dwarfs carried the same d_2 gene.

Crosses among four non-d_2 dwarfs produced tall plants in F_1, and F_2 plants segregated into 9:7 or 9:3:4 ratios, indicating that the four dwarfing genes are nonallelic. The four new dwarf genotypes are from Niger, Mauritania, and ICRISAT. Besides reduced height, some of them mature early and have large spikes and grains. The new dwarf genotypes may be used to diversify the source of dwarfing in pearl millet.

About 1630 accessions of diverse origin were classified as restorers/maintainers after crossing with male sterile lines MS 5141 A and MS 111A. Agronomically desirable lines combining earliness and reduced plant height were developed from tall and photoperiod-sensitive West African germplasm by induced mutations.

Passport and evaluation data up to IP 10 000 accessions are now in the computer for documentation and speedy retrieval.

Some examples of the wide variation in chickpea leaves induced by the use of chemical mutagenic agents.

Chickpea Germplasm

Our world chickpea germplasm includes 12 987 accessions from 41 countries. New releases have come from: Ethiopia (392), India (80), and the USSR (6).

Of the original Regional Pulse Improvement Project (RPIP) collection (from the former USAID/IARI (Indian Agricultural Research Institute) RPIP), several were missing from our gene bank. We have since obtained 724 from Pullman, Washington, USA, and 47 from a collection trip to Haryana, India.

Characterization and evaluation continued. At ICRISAT Center, 1430 accessions were grown and descriptions were recorded for 1157. Foliar diseases and soil salinity again ruined our tests at Hissar. Replicated tests of certain sections of the germplasm showed that ICC 11320 and ICC 12234 yielded significantly better than any control (Annigeri, L 550, G 130). Three of 11 stunt virus-resistant accessions, compared for yield with three controls were marginally superior to Annigeri. Yield evaluation of germplasm from Karnataka showed 21 of 78 accessions equal to Annigeri. Highest yielder (ICC 10398) produced 2628 kg/ha compared with 1400 by Annigeri.

We successfully induced variability in chickpea through chemical mutagens and isolated more than 300 types morphologically different from the parent cultivar, Chafa. Agronomically superior mutant progenies are being tested for yield potential. Certain mutant forms such as plants with kidney-shaped pods, thick stems, and glabrous shoots were noticed in the genus for the first time. Some mutant characters, such as acuminate leaflet shape, or very small leaflets resemble wild species.

Rejuvenation of all annual wild species was successful under extended (24 hr) daylength, but it remains difficult to maintain perennial species at ICRISAT Center. We grew *C. anatolicum*, the plants flowered, but no pods set despite manual pollination. A seasonal change in temperature is required to initiate the perennial root system.

Evaluation data, added to the computer up to

1981-82 harvest, are now retrievable. Passport data of all accessions are stored in the computer catalog.

Chickpea descriptors, long used at ICRISAT and generally accepted by chickpea scientists, were updated and will be published, in collaboration with IBPGR and ICARDA, to replace the prepublication issued in 1979.

Duplicate samples of many ICRISAT chickpea accessions, particularly kabuli types, are maintained at ICARDA.

Pigeonpea Germplasm

Efforts to assemble germplasm from new areas continued, and a joint collecting expedition, organized with the Ministry of Agriculture, Malawi, yielded 230 traditional landraces and 3 wild species, with 200 of the accessions already cleared through National Plant Quarantine Service but not yet released to ICRISAT. Other materials cleared or awaiting clearance include accessions from Nigeria (17), Sierra Leone (7), Sudan (4), and Caribbean Islands (24). A pointed collection carried out in one of the main areas of diversity, the Eastern Ghats of Orissa and Andhra Pradesh, India, resulted in 213 diverse accessions, mainly mid-late maturing.

Total accessions in the gene bank were reduced to 9648 by eliminating duplicates. Of 837 entries, earlier selected on the basis of flower or seed color 324 proved to be duplicates when numerous other morphological traits were compared. Hundreds of recently collected accessions await registration.

On a trip to Chota Nagpur, Bihar, India, to collect and verify related wild species, we secured more accessions of *Atylosia platycarpa* and *A. scarabaeoides*. Forest degradation in that area concerns us. *Rhynchosia orthobotrya* and *Eriosema ellipticum*, both species of the subtribe Cajaninae from Malawi, are new additions to our collection of closely-related species.

A total of 258 Kenyan accessions and 42 lines recently assembled from other countries were grown in the PEQIA for seed increase and release. They include 83 lines from Kenya, detained by the National Plant Quarantine Service until seedlings from healthy seeds could be released. Transplanted in the isolation field, the seedlings established satisfactorily, and started flowering in late 1983.

Germplasm botanist examines a wild relative of pigeonpea in Bihar, India.

For rejuvenation, 338 lines were raised in the postrainy season. Plant stand and flowering are excellent, so seed of all registered accessions is available to meet requests.

In 1983, more than 900 lines were sown for characterization, but since soil asphyxiation by waterlogging prevented data collecting, the plants were used for seed increase. Physiologists used the opportunity to screen against waterlogging and selected many lines for further testing. In general, late-maturing cultivars withstood waterlogging better than the medium-maturing ones.

To characterize extra early- and early-maturing pigeonpeas where they are needed, we evaluated at Hissar 220 lines that matured early

Field workers gather seeds from pigeonpea germplasm rejuvenation plot at ICRISAT Center; 338 such lines were raised in the postrainy season 1983.

at ICRISAT Center. Most lines were considerably later at Hissar than at ICRISAT, which gave breeders from ICRISAT and elsewhere an opportunity to select parents.

We evaluated a set of 36 elite germplasm lines of medium maturity in a replicated trial for yield potential. ICPs 528, 1214, 6982, 7348, 7915, 8142, and 10023 yielded as much as BDN 1 or ICP 8858.

Initial screening for photoperiod insensitivity was carried out by sowing 900 medium to late-maturing lines at different times during the year. All except ICP 7583 were sensitive. Data from screening under extended light begun in 1982-83 and continued in 1983-84, confirmed daylength insensitivity of several lines. Of 400 lines under extended light (20 hrs) during the short days of the postrainy season of 1982-83, 326 flowered, while all controls flowered. Extension of daylength substantially increased total biomass production; plant height increased on average 165%; leaf area, 103%; number of primary branches, 137%; and secondary branches, 415%. But the average delay in days to flowering was only 17%. Some lines were segregating for photoperiod sensitivity, so we initiated purification of relatively insensitive lines.

In an attempt to locate new sources for high seed protein and sulphur amino acids, ICRISAT biochemists analyzed 85 accessions belonging to 19 species of *Atylosia* and *Rhynchosia*. The results confirmed again that wild relatives are good sources for seed protein, methionine, and cystine. Seed protein content of every tested wild species was higher (34% in *Atylosia lineata*) than pigeonpea's 22.4% average. Sulphur amino acid contents were higher in wild species, 2.93 g/16gN in *A. scarabaeoides* than in pigeonpea, 2.01 g/16 g N. The mentioned species are readily crossable with pigeonpea and various introgressed generations are available at ICRISAT. Seed protein estimates of 549 new germplasm lines were entered in the computer catalog.

Pathologists screened 3545 accessions for wilt, sterility mosaic, and stem blight, and entomologists screened 98 new lines for pest resistance.

Passport data of all accessions are available on computer, and evaluation data are entered up to the 1982-83 harvest.

Groundnut Germplasm

Collaborating with Ahmadu Bello University, we sent a collection expedition to northern Nigeria where 81 accessions of cultivated groundnut were collected. An expedition to Brazil resulted in 34 new wild accessions and a few cultivated ones. During the year 458 samples were transplanted in the PEQIA for quarantine inspection and seed increase.

After quarantine clearance accessions from: Japan (16), Rwanda (2), Surinam (1), Tanzania (42), USA (240), Zimbabwe (42), and from other places via The Netherlands (4) were released. During the postrainy season, 133 new introductions and 3409 lines from our gene bank were planted for seed increase and evaluation at ICRISAT Center. During the rainy season, we planted 2257 accessions from: Bolivia (86), Japan (10), Rwanda (2), Surinam (1), Tanzania (39), USA (79), Zimbabwe (9), and other countries via UK (2); along with erect (1025), and spreading bunch types (177), runners (86) and others (741) for evaluation, rejuvenation, and multiplication.

A working collection of 700 cultivars was tentatively constituted by geographical distribution, botanical groups, and agronomic desirability under ICRISAT Center conditions. Some 53 lines were selected for conspicuous morphological characteristics.

Passport data on more than 8000 accessions were tabulated for computerization and data retrieval.

Minor Millets Germplasm

The 217 new accessions collected from India were rejuvenated during the year, raising the total to 4512. The National Plant Quarantine Service released 245 accessions from: Burundi (1), Ethiopia (4), Japan (164), Mexico (15), Mozambique (1), Sudan (1), Tanzania (14), Zambia (8), and Zimbabwe (12). We assembled another 253 accessions from Zimbabwe (223) and other countries via UK (30). They are in the PEQIA awaiting release.

Using funds provided by IBPGR, we worked on the *Echinochloa* and *Paspalum* collection, and characterized and classified 517 accessions of *Echinochloa* and 308 accessions of *Paspalum*, using newly published descriptors.

Requests for germplasm samples of minor millets are increasing (see Table 3). We have distributed 20 075 samples since ICRISAT became responsible for minor millets germplasm.

Looking Ahead

Collection efforts will continue in areas of genetic diversity, with priority on centers facing genetic erosion. New collection missions depend on the availability of funds, and on collaboration and permissions from priority areas.

Multilocation evaluation of our germplasm at selected locations, and rejuvenation in areas of adaptation, will be valuable in the battle for genetic conservation and utilization.

Our computer data storage and retrieval system works well so computer operations will be expanded, diversified, and popularized.

Introgression will continue where necessary to enhance material of possible use in transferring genes from wild species. Along with our continued monitoring of seed viability, we look forward to studying our conserved material in depth.

Links exist with IBPGR, the National Seed Storage Laboratory (NSSL) at Fort Collins, USA; The Royal Botanic Gardens, Kew, UK; and several national programs. The special link with ICARDA for chickpea germplasm work will continue.

Cooperation with national programs that usually starts with collection efforts, carried out with cooperators in the areas of collection will be further strengthened by germplasm exchange, evaluation, and utilization.

Regional Centers, like those being established, or planned in Kenya, Malawi, Niger, and Zimbabwe, will provide a much-needed role in evaluating and maintaining germplasm close to its area of origin. And duplicating collections in such centers will facilitate seed supplies.

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SORGHUM

Contents

Physical Stresses 15
- Drought Resistance 15
- Postrainy Season Adaptation 17
- Factors of Crop Establishment 19

Biotic Stresses 20
- Diseases 20
  - Grain Molds 20
  - Charcoal Rot (*Macrophomina phaseolina*) 23
  - Downy Mildew (*Peronosclerospora sorghi*) 25
  - Anthracnose (*Colletotrichum graminicola*) 26
  - Rust (*Puccinia purpurea*) 27
  - International Sorghum Leaf Disease Nursery (ISLDN) 27
  - *Striga* 28
- Insect Pests 29
  - Shoot Fly (*Atherigona soccata*) 29
  - Stem Borer (*Chilo partellus*) 30
  - Sorghum Midge (*Contarinia sorghicola*) 31
  - Head Bug (*Calocoris angustatus*) 33
  - Armyworm (*Mythimna separata*) 34
  - Neem in Pest Control 35

Biological Nitrogen Fixation 36
- Nitrogen Balance Studies 36
- ^{15}N Isotope-Dilution Technique 37
- Effect of Mineral Nitrogen on C_2H_2 Reduction 37
- Root Exudates and Growth of Nitrogen-fixing Bacteria 37

Plant Improvement 39
- Population Improvement 39
- Evaluation of Advanced Elite Varieties 40
- Female Parents for Hybrids (Male Steriles) 41
- Hybrid Evaluation 43

Food Quality 44

International Cooperation 47
- International Sorghum Variety Adaptation Trial (ISVAT-82) 48
- International Sorghum Hybrid Adaptation Trial (ISHAT-82) 48
- Contribution to National Programs 49
  - West Africa 50
  - Eastern Africa 57
  - Latin America and the Caribbean 58

Workshops, Conferences, and Seminars 60

Looking Ahead 61

Publications 62

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SORGHUM

The main objective of the Sorghum Improvement Program continues to be development of high-yielding, stable varieties and hybrids with acceptable food quality. To meet this objective, we concentrated on developing or improving screening techniques for physical (abiotic) and biological (biotic) yield-limiting factors; screening germplasm and breeding material for sources of resistance and other desirable plant and grain-quality traits, and utilizing the material identified in the breeding program.

This report covers research results obtained in 1982/83 postrainy season and the 1983 rainy season. Data for the 1983/84 postrainy season will be reported in the 1984 Annual Report.

Our major research activities were concentrated at ICRISAT Center. We also used several locations in India where high stress factors occur regularly to adequately screen germplasm and breeding material for resistance to various stresses. The locations for stem borer and anthracnose, are Hissar and Pantnagar, both in northern India, Anantapur in southern India for drought; Bijapur and Akola for *Striga*; Dharwar for sorghum downy mildew and midge, and Bhavanisagar (near Coimbatore) for evaluation of material for tropical adaptation.

Progress was good in improving and standardizing our screening techniques for various abiotic and biotic factors, which enabled us to screen germplasm and breeding lines with more confidence. We identified material with drought-resistant traits, capable of emerging through hot, crusted soils, resistant to grain molds, downy mildew, and leaf diseases, *Striga asiatica*, midge, shoot fly, and stem borer.

Several of our newly-bred male steriles were evaluated for combining ability. A hybrid, ICSH 155, produced on MA 10, gave the highest grain yield, significantly outyielding the commercial hybrids. Our male steriles are now more diverse in plant type, and several resist leaf diseases and have acceptable food quality. A few resist downy mildew.

We conducted several international multilocational disease and insect pest nurseries and adaptation trials in Asia, Africa, and the Americas to learn more about the resistance stability of identified resistant material, and adaptation of improved varieties and hybrids over a wide range of environments. Our cooperators in those countries evaluated the material and selected varieties and hybrids suitable for their environments for further testing or to use in breeding programs.

A number of our varieties and hybrids were evaluated in advanced multilocational national trials. ICSV 108 (SPV 386) was released in Zambia and tested in minikit trials in India in 1983. ICSV 1 (SPV 351) was recommended for release in India. Another variety, SEPON 80-1 (SPV 476), is in prerelease tests in the Yemen Arab Republic.

Physical Stresses

Drought Resistance

Germplasm screening. We further intensified screening of germplasm lines for drought resistance traits under simulated drought conditions at ICRISAT Center in summer, and during the rainy season at Anantapur, a drought-prone location. Since 1977 more than 2000 germplasm lines have been evaluated for yield at various locations in India and Sudan. During the 1983 rainy season, selected germplasm and breeders' lines were screened with two sowing dates. Mid-season stress was observed in the first sowing, and terminal drought in the second. Data from the best germplasm lines screened at Anantapur are compared with data from common controls or released hybrids (Table 1). M 35-1, drought resistant under terminal stress during the post-rainy season in India, did not perform so well under the rainy season conditions. Highly significant interactions between date of sowing (pattern of drought stress) and genotypes were seen for most variables studied. Only three of the ten top-performer lines on each sowing were common: DJ 1195, IS 22314, and IS 22380. Lines found promising under drought originated from different geographical regions, and belonged to both early and medium-maturity groups (Table 1). Most late-maturing entries were photosensitive, tall, and yielded much dry matter, with low grain yields. In addition lines were screened in the summer for physiological traits, such as desiccation tolerance and recovery after severe

Table 1. Grain and dry-matter yield, and days to flower of selected sorghum lines and controls for early (8 June) and late (3 August) planting, Anantapur, 1983.

		Sowing date 8 June			Sowing date 3 Aug		
Pedigree	Origin	Grain yield g/m²	Dry matter g/m²	Days to flower	Grain yield g/m²	Dry matter g/m²	Days to flower
Selected germplasm entries							
IS 22270	Botswana	148	370	62	103	801	55
IS 22291	Botswana	86	429	70	60	624	63
IS 22299	Botswana	142	427	65	86	748	53
IS 22307	Botswana	145	429	63	82	707	54
IS 22308	Botswana	126	383	60	89	770	60
IS 22314	Botswana	153	391	63	121	658	54
IS 22315	Botswana	107	334	59	73	656	54
IS 22316	Botswana	122	452	73	54	640	68
IS 22353	Botswana	159	438	60	101	789	53
IS 5642	India	39	1334	101	133	1418	74
IS 8315	India	71	1198	94	93	1900	64
IS 2312	Sudan	99	1016	94	58	1408	76
IS 22380	Sudan	117	531	67	107	628	55
Common controls							
M 35-1	India	26	963	87	33	1186	76
DJ 1195	India	115	558	76	103	930	59
V 302	India	34	354	80	18	561	67
CSV 5	India	42	868	90	18	588	80
Hybrids released in India							
CSH 5	India	82	861	85	114	1239	70
CSH 6	India	82	295	70	124	888	58
CSH 9	India	65	906	86	126	1144	67
SE		±19.5	±144.8	±5.5	±19.2	±199.7	±2.8
CV (%)		60	40	18	52	34	13
Mean[1]		63	792	86	70	1093	69

[1] Mean for all 93 entries in the trial.

desiccation. These lines will be further screened in 1984.

Postrainy Season Adaptation

Adaptation to cooler temperature in India. More than one-third of Indian sorghum (6.5 million hectares) is grown with stored soil moisture during the postrainy season. Yield improvement during this season has been slow.

Physiological aspects of sorghum adaptation and the role of nitrogen under receding soil moisture during the postrainy season in relation to leaf area, dry matter, and grain yields were discussed in the 1977/1978, 1979/1980, and 1982 ICRISAT Annual Reports.

To investigate the reasons for declining yields with delayed sowing, we conducted experiments in the postrainy seasons of 1979 and 1982. Sorghum was sown on four dates on Vertisols from September to November (hereafter referred to as S_1 to S_4 crops). Treatments included dryland and irrigated crops, with four replications. Grain yields decreased with later sowings in 1979 (Fig. 1). The trend was similar in 1982, except that the last sown S_4 crop yielded higher than the S_1 crop of CSH 8R despite S_4's, shorter (7 days) grain-filling period (Table 2). Irrigation effects were generally greater with delayed sowing (Fig. 1).

We attempted to relate grain-yield variation from successive sowing times with climatic

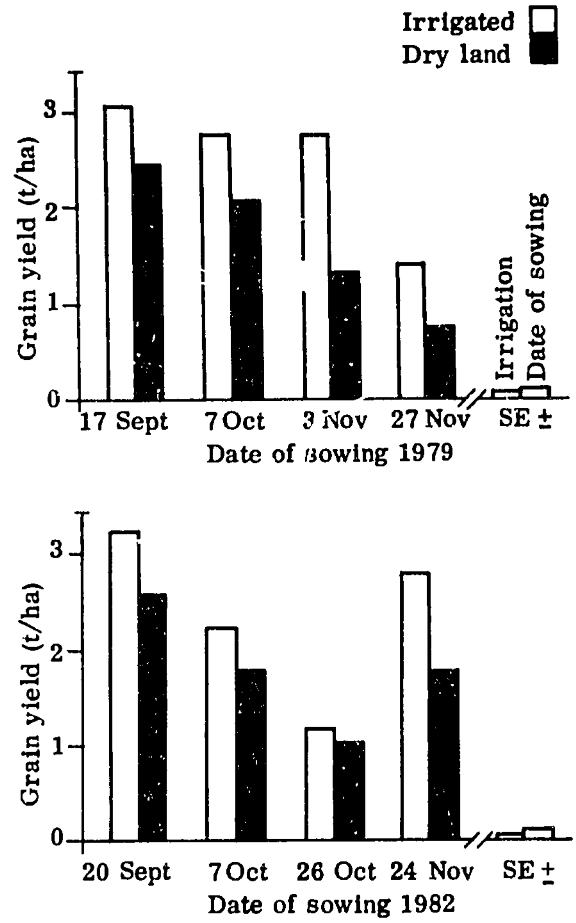


Figure 1. Grain-yield response of sorghum to irrigation and date of sowing during postrainy seasons 1979 (A) and 1982 (B). (Mean of 5 cultivars).

Table 2. Effect of date planted on grain and biomass yield, yield components, phenology, and plant height of irrigated sorghum CSH 8R crops, ICRISAT Center, postrainy season 1982.

Crop date planted	S_1 20 Sept	S_2 7 Oct	S_3 26 Oct	S_4 24 Nov	SE	Mean
Grain yield (kg/ha)	2870	1940	1330	3120	±249	2316
Biomass (kg/ha)	9860	7030	5860	8890	±464	7911
Harvest index (%)	29.2	27.8	22.6	35.0	±2.1	28.6
Plant height (cm)	164	147	132	118	±4.6	140
Days to flower	62	69	69	81	±0.4	70
Days to maturity	103	107	108	115	±1.0	108
Seeds/m^2 × 10^3	15.8	12.6	8.1	9.3	±1.2	11.4
Seed wt (g/100 seeds)	1.82	1.55	1.71	3.37	±0.1	2.11

changes while each S_1 to S_4 crop was in its growth stage. Only the data from the irrigated CSH 8R plots in 1982 are presented; the trend was similar across years and irrigation treatments.

Maximum leaf-area index decreased with successive sowings (Fig. 2), but leaf-area persistence during grain filling was highest in the S_4 crop. Dry-matter production declined with successive sowings (Fig. 2). In the S_4 crop, however, it increased rapidly after flowering.

Temperature data from sowing to maturity from each S_1 to S_4 crop showed that the minimum temperature declined with each successive planting, except for an increase during S_4's grain-filling period. Examination of the leaf-area and dry-matter curves (Fig. 2) and the temperature fluctuations during crop growing periods suggests that growth was affected mainly by changes in minimum temperatures. Plant height also was reduced with successive sowings (Table 2). Similarly lower temperatures during grain filling of S_2 and S_3 crops reduced grain yields.

The S_4 crop was subjected to the coolest temperature of any crop, which substantially delayed its flowering and resulted in a higher sink potential than in the S_3 crop (compare seeds/m^2 in Table 2). The higher dry-matter accumulation during the terminal growth stage (Fig. 2) and higher grain yields by the S_4 crop were possible because adequate leaf area was functioning under nearly optimum air temperature (and evaporative demand for water). The S_4 crop had the biggest seed size and highest harvest index (Table 2).

The results underline the need for better understanding of temperature effects on plant processes during each growth stage. Also the interactions of different environmental effects in determining yield in the postrainy season should be studied.

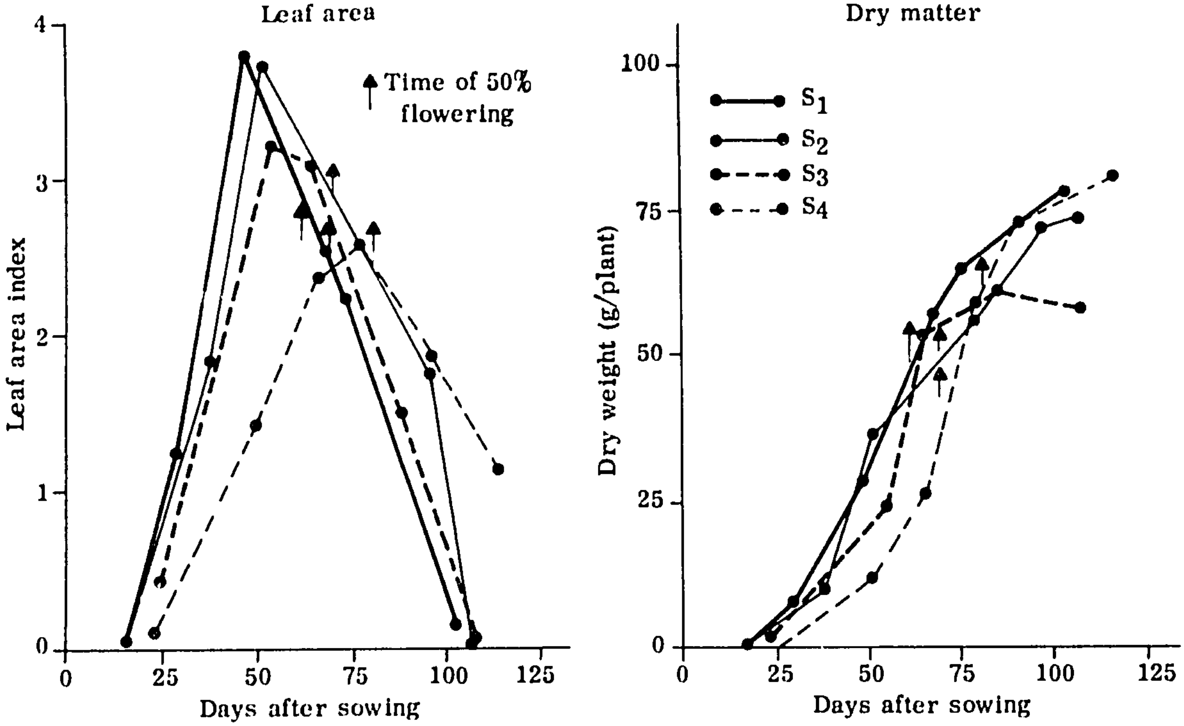


Figure 2. Changes in leaf area (left) and dry-matter accumulation (right) in irrigated crops of CSH 8 planted on four dates (S1 = 20 Sept; S2 = 7 Oct; S3 = 26 Oct; S4 = 24 Nov) in 1982.

Factors of Crop Establishment

Genotype response to emergence at high soil temperature. A technique to study seedling resistance to high soil temperature was reported earlier (ICRISAT Annual Report 1982, p.41). Selected sorghum and millet lines were screened at temperatures of 35, 40, 45 and 50°C. Table 3 shows the effects of different soil temperatures on emergence of a few advanced sorghum breeding and germplasm lines, selected from a field experiment for ability to emerge through simulated soil crust (reported under Pearl Millet). The 3 top-ranking lines for emergence through soil crust also have high emergence at 45°C, the screening temperature selected earlier.

Table 3. Effect of soil temperature (° C at 20 mm depth) on seedling emergence in breeders' and germplasm lines. The sorghum lines were selected from a field trial on ability to emerge through crusted (capped) soil.

Entry	Seedling emergence (%) at indicated soil temperatures (°C)				Rank position for emergence through soil crust
	35	40	45	50	
Breeders' material					
D 38093	97	87	87	53	2
D 38061	87	83	77	53	3
D 38060	87	83	53	63	9
D 38138	90	73	73	53	13
D 38133	80	50	40	3[1]	14
D 40011	57	43	33	27	130
D 40020	47	37	17	0[1]	132
D 40025	73	63	70	33	135
D 38230	90	70	77	53	136
D 38236	67	53	70	20	150
SE	±4.8	±5.4	±6.8	±6.8	
Mean	77	64	57	36	
Germplasm					
IS 2877	-	97	77	53	1
IS 1045	-	100[1]	97	47	8
IS 18530	-	90	97	60	10
IS 1004	-	70	57	33	16
IS 18529	-	67	87	50	19
IS 1022	-	70	90	67	21
IS 84	-	77	77	67	25
IS 2874	-	100[1]	97	50	28
IS 1109	-	100[1]	67	30	33
IS 5109	-	97	67	33	44
SE	-	±4.2	±4.4	±4.0	
Mean	-	87	81	49	

[1] Entry values not included in calculating standard error.

Variability in plumule growth. A faster-growing plumule is considered advantageous for improved seedling establishment, especially under unreliable early rains and heat stress. Forty seeds each of 16 sorghum lines were germinated in an incubator at 31 ± 1.4°C, between two filter papers juxtapositioned on either side of a piece of hardboard supported by a perspex frame in a plastic box. The filter paper was kept wet by adding water until it reached the lower portion of the filter paper. Plumule lengths were recorded every two hours by noting the extension on the vertical graduated metal wire positioned by each seed. Plumule increases followed a linear pattern, so the slope of a simple linear regression of length on time was taken as the plumule growth rate. The final value recorded indicated the plumule's total length. Figure 3 shows significant cultivar differences in plumule growth rates; at 31°C the hybrid CSH 6, grew less than 0.4 mm/hr, while SPV 354 grew more than 1.0 mm/hr.

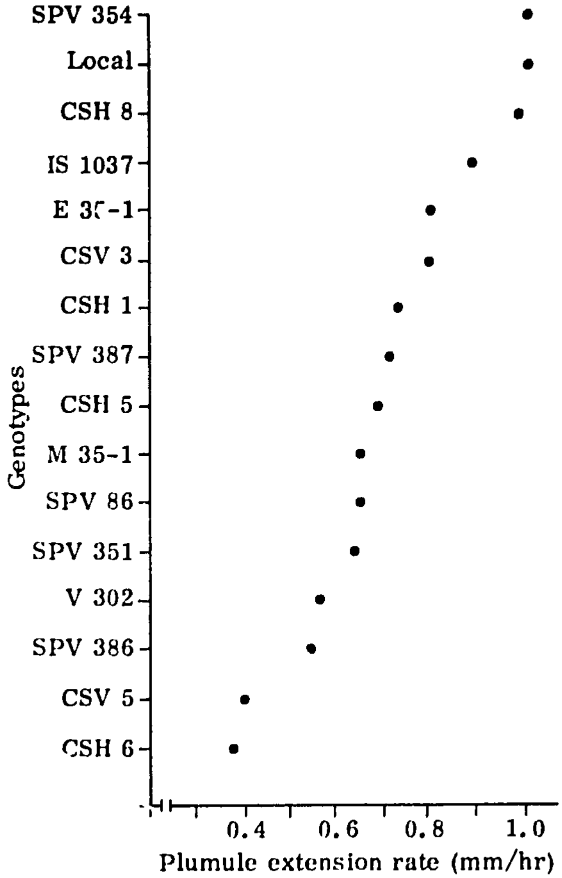


Figure 3. Variability in growth rates of plumules in some sorghum genotypes grown in an incubator at 31±1.4°C.

Biotic Stresses

Diseases

Grain Molds

Screening germplasm for resistance. We completed screening the sorghum germplasm collection for resistance to grain molds caused by a complex of several fungi. Reliable data were obtained from only 3644 of 22466 lines in the collection, which (a) flowered not later than 78 days from emergence and, thus, matured under weather conditions that favored mold development, (b) grew up to 2.8 m, to be reached by spray from sprinklers used to provide a moist environment for mold development, and (c) produced seeds not completely covered by glumes. We identified 74 colored-grain lines of diverse origin with high resistance to molds and weathering. Table 4 gives data for selected entries from three years' screening at ICRISAT Center.

Association of causal fungi. For three seasons in 1981 to 1983 we studied in replicated field experiments the pattern of natural infection and colonization of developing sorghum grain by mold causal fungi in the mold-susceptible lines 2077B and CSH 1. Fungal isolations were made from the ovary at the anther-shedding stage and then at five grain-development stages: (a) soft-dough green, (b) hard-dough green, (c) hard-dough yellow, (d) black layer formation (maturity), and (e) one week after maturity but before harvest.

Fusarium moniliforme was the fungus most frequently isolated from developing ovaries and its frequency increased as the grains developed. *Curvularia lunata* also was isolated, at lower frequency, from ovaries at anther-shedding but its frequency increased with grain development.

In 1981 and 1982 *Phoma sorghina* was most frequently (up to 40%) isolated from the soft-dough green stage onward, whereas in 1983 it was seldom isolated. From the soft-dough green stage to maturity, more than one fungus was isolated from the same grains, and types of fungi isolated increased gradually as grains developed and matured. Associations of *Fusarium* spp with *Curvularia lunata* were found in 40% of the grains. Other associated fungi were *Curvularia* sp with *Phoma* sp and *Fusarium* sp with *Curvularia* sp, and *Phoma*.

Tannin and resistance. The few published reports on grain mold resistance indicate that tannins are responsible for resistance in colored-

Table 4. Days to 50% flowering (DTF), panicle grain mold rating (PMR), threshed grain mold rating (TMR), and germination percentage of selected colored-grain sorghum lines during screening, ICRISAT Center, 1981-1983.

			1981	1982			1983		
Sorghum line	Origin	DTF[1]	PMR[2]	PMR	TMR[3]	Germ. (%)	PMR	TMR	Germ. (%)
IS 620	Unknown	54	1.5	2.7	2.0	75	2.0	2.6	68
IS 2453	USA	60	2.6	1.8	2.0	84	2.0	1.9	93
IS 2454	USA	57	2.6	2.1	1.7	92	2.0	2.0	88
IS 2560	USA	57	2.6	1.6	1.6	97	1.8	2.0	73
IS 6047	India	61	2.9	2.5	2.0	99	2.0	2.4	93
IS 6335	India	55	2.3	2.0	3.5	97	1.8	2.0	99
IS 7237	Nigeria	60	2.4	2.1	2.0	95	2.0	2.0	93
IS 8219	Uganda	59	3.0	2.1	2.0	91	2.0	2.0	87
IS 8525	Ethiopia	55	2.5	3.1	2.0	94	2.0	2.0	86
IS 9308	Africa	58	1.6	2.5	2.0	92	2.0	2.0	92
IS 9471	S. Africa	61	2.2	1.6	1.4	98	2.0	2.0	91
IS 9482	S. Africa	63	2.2	1.6	2.0	95	2.0	2.0	94
IS 9494	S. Africa	58	2.7	2.5	2.0	98	2.0	2.0	74
IS 11234	Ethiopia	60	2.4	2.4	2.1	97	2.2	2.0	72
IS 79	Mexico	63	1.5	1.8	2.0	97	2.2	2.3	82
IS 529	USA	63	1.6	1.6	1.4	88	2.0	2.0	88
IS 9804	Sudan	59	2.2	1.8	2.1	96	1.7	2.0	97
IS 10942	USA	54	1.2	1.6	1.2	96	2.0	2.0	92
IS 18528	India	59	2.6	2.2	1.7	92	2.0	2.0	81
IS 21498	Malawi	71	2.7	2.7	1.7	95	2.0	1.8	97
IS 623	USA	62	2.0	1.9	1.7	85	2.0	2.0	90
IS 624	USA	65	2.1	1.8	2.0	84	2.0	2.0	81
IS 4006	India	61	2.5	1.6	1.8	86	1.9	2.0	92
IS 9470	S. Africa	64	2.2	1.9	1.6	85	2.0	2.2	75
CSH 1[4]	India	57	5.0	5.0	5.0	36	4.5	5.0	39
SPV 104[4]	India	67	5.0	5.0	5.0	8	5.0	5.0	7
SE				±0.37	±0.82	±6.4	±0.10	±0.26	±5.0
CV (%)				20	19	11	7	17	9

1. Mean of years 1981-1983.
2. Panicles in the field evaluated on a 1 to 5 scale where 1 = no mold and 5 = severe mold with > 50% grains/panicle molded.
3. Threshed grains evaluated on a 1 to 5 scale where 1 = no mold and 5 = severe mold with > 50% grain surface area molded.
4. Susceptible controls.

grain sorghums. Identification of high mold resistance in colored-grain genotypes without the tannin-containing testa layer (ICRISAT Annual Report 1982, p.27) prompted us to investigate the relationship between mold resistance and tannin content. In collaboration with the Biochemistry Unit, we analyzed for tannin the developing grain of 12 genotypes at 10-day intervals from soft-dough stage (SDS) to 10 days after the black layer formed (grain maturity). We analyzed for the content of tannins types I and II using the vanillin assay method. Grain mold data were taken on the same samples used in the tannin analyses.

Tannin content was high (21-26 catechin equivalent (CE %) at SDS and 10-11 CE % 30 days after SDS) in IS 79, IS 625, IS 707, IS 2354, and IS 9804; intermediate in IS 3522 (10 and 4 CE %, respectively, at SDS and 30 days later); and negligible in IS 402, IS 417, IS 655, IS 14375, IS 14384, and IS 14390 (0.0-0.5 CE %). But grain mold ratings at grain maturity and 10 days later were low (2.0-2.4 on the 1 to 5 scale where 1 = no mold and 5 = severe mold) in all the lines with high and moderate tannin content as well as in three lines (IS 14375, IS 14384, and IS 14390) with negligible amounts of tannin. The results indicated that grain-mold resistance, in some cases, is not associated with tannins. Other compounds that may be responsible for resistance are being investigated in collaboration with the Biochemistry Department of Purdue University, USA.

International Sorghum Grain Mold Nursery (ISGMN). The 1982 ISGMN consisting of 27 test entries and 3 susceptible controls for early, medium, and late maturing groups was grown by cooperators at 23 locations in Africa, Asia, and the Americas. Conditions favored mold development (frequent rainfall, high humidity and temperature during grain filling and maturity) at 8 locations: Bhavanisagar, Pantnagar, and ICRISAT Center (India), Sete Lagoas (Brazil), Casamance (Mexico), Laguna (Philippines), Farm Suwan (Thailand), and Farako Bâ (Upper Volta). The best entries were IS 10301 and IS 10892, which were resistant at all locations. Next best were IS 79, IS 529, IS 625, IS 8848, IS 9353, IS 9487, and IS 20620, which were resistant at 7 locations.

Breeding for resistance. Using the grain-mold screening techniques developed earlier (ICRISAT Annual Report 1981, p. 32), we screened, for the first time, several F_1, F_2, and F_3 progenies derived from crosses between mold-resistant, colored-grain sorghums and susceptible white-grain sorghums to see if white-grain segregates with high mold resistance could be identified. All the F_2s had colored grain and were mold resistant. The F_1s of crosses between a mold-susceptible colored line (Q 953) and mold-susceptible, white-grain lines (SPV 104 and 351) had colored grain but were mold susceptible.

As expected, frequencies of white-grain segregates in F_2s were low and variable. Still we identified 61 white-grain segregates with good mold resistance (Table 5), 8 of which had mold-resistance levels similar to their colored-grain parents. Most of the F_2 segregates of both grain colors derived from crosses between mold-susceptible, colored-grain and mold-susceptible, white-grain sorghum parents molded severely. Few segregates of either grain color had low mold resistance, indicating transgressive segregation.

We also screened approximately 4783 F_3 progeny rows derived from F_2 selections made during the 1982 postrainy season in the absence of grain mold but with high selection pressure for white-grain segregates. Approximately 410 white-grain, mold-resistant individual panicles were selected.

Identification of white-grain, mold-resistant segregates confirms earlier observations, (ICRISAT Annual Report 1982, p. 27) that grain-mold resistance is not always associated with colored grains. So we have more confidence in breeding to transfer mold-resistance genes from colored-grain to white-grain sorghum types.

All the mold-resistant selections, including a great many with colored grains will be screened for grain-mold resistance in the 1984 rainy season. The mold-resistant, colored selections are

Table 5. Results of screening for mold resistance of F_2 segregating progeny derived from crosses between mold-resistant, colored-grain sorghums and mold-susceptible, white-seeded sorghums at ICRISAT Center, rainy season 1983.

Pedigree	Total Screened	Seed color segregation		Mold-resistant selections	
		Colored	White	Colored	White
IS 14384[1] × SPV 351	550	502	48	406	12
IS 14384[1] × SPV 104	340	281	59	227	12
SPV 351 × IS 14385[1]	554	402	152	354	18
SPV 104 × IS 14385[1]	561	493	68	338	15
IS 14388[1] × SPV 104	627	550	77	318	2
IS 14388[1] × SPV 351	521	458	63	358	1
IS 2333[1] × SPV 104	507	426	81	255	1
IS 2333[1] × SPV 351	328	301	27	214	0
Total	3988	3413	575	2470	61

1. Mold-resistai. 'olored-grain sorghum parent.

heterozygous for grain-color genes and many are expected to continue to segregate for white-grain types in subsequent generations.

Charcoal Rot (*Macrophomina phaseolina*)

Effect of moisture stress and charcoal rot on yield. To determine grain yield losses caused by combined effects of moisture stress and charcoal rot, we conducted an experiment during the 1981 postrainy season at ICRISAT Center, Dharwar, and Nandyal (India), and at Wad Medani (Sudan). The design was a split-split plot with four moisture stress treatments as main plots and three plant population densities (66675, 133350, and 266700 plants/ha) of a highly susceptible sorghum hybrid, CSH 6, as sub plots in six replications.

Moisture stress predisposed plants to infection by charcoal rot, which was determined by recording root infection, stalk infection (soft stalk), and extent of infection up the stalk from the crown (no. of nodes crossed). Since those factors were highly and significantly correlated with lodging (Table 6), only lodging is considered in the results. Yield was determined from both standing and lodged plants.

Sorghum plants devastated by charcoal rot (*Macrophomina phaseolina*), moisture stress predisposes plants to infection.

Table 6. Correlation coefficients among factors of charcoal rot disease scores under depleted soil moisture conditions in plant population densities at four locations, ICRISAT Center, Dharwar, Nandyal (India) and Wad Medani (Sudan).

Disease	Soft stalk (%)	Mean no. of nodes crossed	Mean score for root infection[1]
Lodging (%)	0.96	0.88	0.57
Soft stalk (%)		0.88	0.52
Mean no. of nodes crossed			0.47

1. Based on Indian locations.

Results (Table 7) show grain yield losses of 23 to 64%. Future experiments will attempt to partition loss in grain yield caused by charcoal rot and the predisposing effect of moisture stress.

Nonsenescence trait as an indicator of resistance. During 1981 we conducted two experiments to study the relationship of the nonsenescence (stay-green) trait and charcoal rot incidence under natural infection. In the first experiment, test genotypes were grown near the end of rainy season so grain filling was under increased drought stress.

Seventy-nine sorghum lines, previously identified by sorghum physiologists at ICRISAT Center as nonsenescent (<3 on a 1 to 5 leaf and plant-death rating, where 1 = completely green; 5 = completely dead), were grown at four locations in India, in single rows each 4m-long in two replications. A senescent hybrid, CSH 6, was sown as a susceptible control.

Planting dates in 1981 were 5 Sept Madhira, 15 Sept Dharwar, 12 Oct Nandyal, and 14 Oct ICRISAT Center. The experiment was conducted on Alfisol at ICRISAT Center and on Vertisols at other locations. A normal plant population of 133 350 plants/ha was maintained, and crop protection to control insect pests was intensive.

The set of 79 lines, as in the first experiment, was planted in a split-split plot design with two replicates at Dharwar in the postrainy season under irrigation. Main treatments were four soil-moisture stress levels. The plant population was 133 350 plants/ha and each plot consisted of two rows each 4 m long. Selected crop physiological characteristics and charcoal rot were measured and compared.

Data in Table 8 show considerable variation in leaf and plant death (LPD) scores of selected genotypes across locations. For example, IS 108 had low LPD scores (<3) at ICRISAT Center

Table 7. Effect of charcoal rot (as measured by % lodging) on sorghum plot yield ($kg/18m^2$) for moisture-deficiency stress levels at four locations during 1981.

Irrigation treatments[1]	ICRISAT Center (India)		Dharwar (India)		Nandyal (India)		Wad Medani (Sudan)	
	Lodging (%)	Yield	Lodging (%)	Yield	Lodging (%)	Yield	Lodging (%)	Yield
T_1	8	2.2	7	3.3	1	3.0	3	2.1
T_2	42	2.2	86	2.5	2	2.0	5	1.9
T_3	46	1.8	100	2.1	36	1.7	56	1.9
T_4	55	1.6	100	1.7	47	1.1	73	1.6
Loss in yield (%)[2]	27		48		64		23	
SE	±3.5	±0.08	±1.9	±0.10	±3.5	±0.17	±3.11	±0.10

1. T_1 = Irrigation to physiological maturity.
T_2 = Irrigation to 50% flowering.
T_3 = Irrigation to boot leaf stage.
T_4 = Irrigation to final leaf in the whorl.
2. $\frac{\text{Irrigation to physiological maturity - irrigation to final leaf in the whorl}}{\text{Irrigation to physiological maturity}} \times 100$. (Applies to stress T_1 and T_4 only).

Table 8. Days to flowering, plant height (m), leaf and plant death, grain weight (g), lodging (%), soft stalk (%), mean number of nodes crossed and mean score for root infection of sorghum genotypes (rated as nonsenescent) at four Indian locations, postrainy season 1981.

Cultivar	Locations	Days to 50% flowering	Plant (m)	Leaf and plant death[1]	1000 grain weight (g)	Lodging (%)	Soft stalk (%)	Mean no. nodes crossed	Mean score root infection[2]
IS 108	Madhira	55	1.7	2.2	23.8	10.2	3.5	0.3	2.2
	Dharwar	47	1.6	4.4	19.9	44.6	37.5	1.1	4.0
	Nandyal	53	1.6	4.5	27.6	40.0	55.0	2.0	4.5
	ICRISAT	56	0.8	2.5	29.8	0[3]	0[3]	0.5	3.0
IS 176	Madhira	65	1.3	3.3	25.5	0[3]	0[3]	0.4	1.5
	Dharwar	59	1.7	4.5	17.1	43.1	62.5	1.6	4.5
	Nandyal	71	1.1	2.4	34.1	5.0	5.0	0.0	3.0
	ICRISAT	70	1.2	4.0	26.4	25.0	40.0	0.7	4.5
IS 2954	Madhira	65	1.2	4.0	27.6	30.0	61.8	1.5	4.0
	Dharwar	61	1.3	3.6	24.8	2.3	5.0	0.1	2.0
	Nandyal	71	1.0	2.6	30.6	0[3]	15.0	0.8	1.9
	ICRISAT	67	1.1	4.5	25.9	20.0	50.0	1.1	5.0
IS 3927	Madhira	59	1.2	2.8	45.7	0[3]	13.3	0.3	2.5
	Dharwar	57	1.1	2.9	34.4	26.2	15.0	0.3	2.0
	Nandyal	60	1.0	3.5	40.6	45.0	50.0	2.8	4.0
	ICRISAT	61	0.7	4.3	50.9	55.0	55.0	1.9	5.0
IS 10722	Madhira	66	1.4	4.0	19.8	48.7	48.7	2.0	4.0
	Dharwar	60	1.2	3.2	24.3	22.8	35.0	0.7	2.5
	Nandyal	71	0.9	2.9	46.3	10.0	20.0	0.8	3.2
	ICRISAT	65	1.1	3.6	31.8	25.0	25.0	0.5	4.5
CSH 6	Madhira	56	1.3	4.9	26.3	83.6	92.3	5.4	4.9
	Dharwar	62	1.5	4.7	25.6	57.4	72.1	2.3	4.8
	Nandyal	67	1.2	4.0	25.2	100.0	100.0	4.7	5.0
	ICRISAT	63	1.1	4.7	26.9	78.7	85.0	2.6	4.7
SE		±4.3	±4.11	±0.51	±8.19	±18.40	±17.80	±1.38	±1.36

1. Nonsenescence ratings: based on leaf and plant death scores where 1 = completely green, 5 = dead.
2. Root infection score where 0 = no discoloration or infection, 5 = more than 50% roots showing infection and discoloration.
3. Not included in the examination of standard errors.

and Madhira but high (>4) at Dharwar and Nandyal. But at all locations, LPD scores correlated highly with charcoal rot disease (Table 9). The results indicate that plant nonsenescence, determined as low LPD score, is useful in selecting charcoal rot-resistant genotypes, also that nonsenescence is not stable across locations, possibly due to environmental factors. Further research is in progress on this topic.

Downy Mildew (*Peronosclerospora sorghi*)

Screening for resistance. We used the large-scale, field screening technique at Dharwar (ICRISAT Annual Report 1982, p. 28) to evaluate 4031 sorghum lines from the germplasm collection, and selected 80 lines with 0 to 5% systemic disease for further screening in 1984. Of the 187 lines selected in 1982 downy mildew

Table 9. Correlation coefficient among charcoal rot disease factors of sorghum lines (reported as nonsenescent) under naturally depleting soil moisture conditions, ICRISAT Center, postrainy season 1981-1982.

Disease factors	Soft stalk (%)	Mean no. of nodes crossed	Mean score for root infection	Leaf and plant death infection
Lodging (%)	0.74	0.47	0.29	0.59
Soft stalk (%)		0.63	0.47	0.76
Mean no. of nodes crossed			0.31	0.50
Mean score for root infection				0.28

(DM) screening with 0 to 5% systemic disease, 17 remained free from the disease and 35 had up to 5% systemic disease. Selected entries of these 52 lines will go into multilocational tests in 1984.

We also screened 168 high-yield-potential, advanced generation breeding lines and 212 B lines; 13 of the breeding lines had up to 5% systemic disease, but 6 of the B lines (A 4434, A 4540, A 4421, A 4606, M 60050, and D 63206) were free from the disease.

Susceptibility of wild and weedy sorghum species. We screened 221 of the 345 wild and weedy sorghum species in the germplasm collection at Dharwar in 1982 and 1983. With 4 exceptions (ICRISAT Annual Report 1982 p.27), they were highly susceptible (50-100% systemic disease) to DM. Wild and weedy sorghum species are widely distributed in sorghum-growing areas where DM occurs. In view of their extreme susceptibility to the disease, their potential role as reservoirs and sources of inoculum in DM areas should be investigated.

Multilocational testing for resistance stability. Data of the 1982 International Sorghum Downy Mildew Nursery (ISDMN) consisting of 17 test entries and 2 susceptible controls were received from cooperators at Dharwar and Mysore (India), Jaboticabal (Brazil), Pergamino and Manfredi (Argentina), and College Station, Texas A&M University, USA. As previously, QL3 and two of its sister lines remained free from DM. A new entry, Nandyal DMRS-KHA, was also free from the disease at all locations. The remaining 13 entries had 1 to 5% systemic disease. After several years of multilocational testing, we now have several sorghum genotypes of diverse origin and phenotypic characteristics with apparent stable resistance to DM.

Breeding for resistance. Approximately 200 progenies in the F_4 to F_8 generations were screened for DM resistance in the large-scale downy mildew screening nursery at Dharwar; 95 progenies, which were as immune as the QL 3 parent, were selected. A total of 294 individual plant selections with desirable agronomic traits were made from the DM-immune progenies for further screening and testing. We also screened 172 F_2 segregating populations derived from crosses involving QL 3 for DM resistance and selected 682 DM-free plants. We distributed 39 advanced DM-resistant lines to the ICRISAT sorghum program based at CIMMYT for screening against DM in the Americas. Thirty-five lines were resistant to pathotype 3 of *P. sorghi* in Texas. Resistance to pathotype 3 had previously been identified in only a few lines in the USA.

A number of DM-resistant advanced lines derived from crosses involving nonrestorers were crossed to two male-steriles (2219A and 296A), and the resulting F_1s were grown during the 1983 rainy season at ICRISAT Center to check their fertility restoration reaction; 40 nonrestorer progenies were backcrossed to their sterile hybrids to convert them to male sterility.

In yield trials, grain yields of eight advanced generation lines (all resistant to DM as the parent QL 3) were nearly double the yield (2590 kg/ha) of QL 3.

Anthracnose (*Colletotrichum graminicola*)

Screening for resistance. At Pantnagar, in northern India, where resistance screening is conducted, from June to mid-September is most favorable for natural incidence of severe anthracnose on susceptible genotypes. Sorghum lines that flower later escape the disease and, thus, cannot be evaluated for resistance. Until 1983 only 6735 of 22466 lines in the sorghum germplasm collection could be evaluated for resistance, and only 10 genotypes were identified as resistant to anthracnose. We also screened 197 advanced generation breeding progenies and 177 B lines, of which 67 breeding progenies and 5 B lines were selected for further screening. Some B lines, such as CK-60-B, 296-B, 36-B, and Kaffinum, which are widely used in producing hybrids, were highly susceptible to anthracnose. They should not be used for hybrids destined to be grown in areas where anthracnose is a problem. In replicated trials 224 lines selected in 1983 gave us only 2 germplasm and 9 high-yield potential breeding lines that were resistant.

Grain yield loss. Loss in grain yield due to anthracnose was determined in an experiment conducted in 1982 and 1983 at Pantnagar. Anthracnose-susceptible genotypes IS 12326 and IS 19640 were grown in a randomized block design with three treatments (a) anthracnose controlled with 7 carbendazim sprays at weekly interval; (b) anthracnose partially controlled by 3 carbendazim sprays at monthly intervals; and (c) anthracnose not controlled. Treatments were replicated three times. In plots with traces of anthracnose (treatment a) grain yield was 3407 kg/ha for IS 12326; 3288 kg/ha for IS 19640. But when 35% leaf area of the top four leaves at the hard-dough stage was damaged by anthracnose (treatment b), grain yield was down 22% for IS 12326 and 27% for IS 19640. Under severe anthracnose pressure (treatment c) 86% and 77% of the leaf area of the top four leaves of IS 12326 and IS 19640, respectively, were damaged at the hard-dough stage, and grain yields were down 40% and 50%, respectively, in the two genotypes.

International Sorghum Anthracnose Virulence Nursery (ISAVN). The ISAVN, coordinated by pathologists at Texas A&M University, aims to identify worldwide physiological races of *C.graminicola*. The nursery consists of anthracnose-resistant and susceptible, race-differential genotypes. All 13 entries of the 1981 ISAVN evaluated at Pantnagar were highly susceptible, including lines resistant in the USA, which indicates possible existence at Pantnagar of pathogen races different from those in the USA.

Rust (*Puccinia purpurea*)

Screening for resistance. During 1983 rainy season at Dharwar, we screened 626 advanced generation breeding lines for resistance and selected 208 lines that had up to 5% leaf area damaged by rust. We also confirmed rust resistance for the third year in 92 high yield-potential, advanced generation breeding lines. The agronomic eliteness of these lines makes them valuable sources of rust resistance in breeding programs.

International Sorghum Leaf Disease Nursery (ISLDN)

Data of the 1982 ISLDN consisting of 28 test entries and 7 susceptible controls were received from cooperators at Oran-Salta, Argentina; Sete Lagoas, Brazil; Nubaria, Egypt; Dharwar, Indore, Kovilpatti, and Pantnagar, India; Laguna, Philippines; Bambey and Nioro, Senegal; Kadugli, Sudan; Farm Suwan, Thailand; and Farako Ba, Upper Volta. Adequate disease pressure for meaningful evaluations was recorded at different locations for anthracnose, leaf blight (*Exserohilum turcicum*), rust, grey leaf spot (*Cercospora sorghi*), zonate leaf spot (*Gloeocercospora sorghi*), sooty stripe (*Ramulispora sorghi*), rough leaf spot (*Ascochyta sorghina*), oval leaf spot (*Ramulispora sorghicola*), bacterial leaf stripe (*Pseudomonas andropogoni*), maize dwarf mosaic virus, and rhizoctonia leaf and sheath blight (*Rhizoctonia* spp). Several lines showed resistance to one or more diseases, with IS 115 and IS 8307 most promising; IS 115 was resistant to all the above diseases except bacterial leaf stripe and grey leaf spot, and IS 8307 was resistant to all except anthracnose, rust, and bacterial leaf stripe.

Sorghum at left is susceptible to *Striga asiatica* seen growing at the base of the plants. The ICRISAT-developed line at right is resistant to the parasitic weed.

Striga

Breeding for resistance. We screened 144 breeding lines for resistance to *Striga* using the preliminary screening Stage II method and identified 45 *Striga*-resistant lines for further testing. Six of the 45 have been selected for advanced stage testing during 1984 rainy season, and were designated SAR 29 to SAR 34.

We evaluated (in checkerboard layout) 18 advanced lines including N 13, a resistant variety, and CSH 5, a susceptible hybrid, in *Striga*-sick fields at Akola and Bijapur in India. Nine entries (Table 10) were selected for good *Striga* resistance and all outyielded CSH 5 at both locations.

Eight lines resistant to *S.hermonthica* in Africa were tested in Stage II (preliminary screening) at Akola, Bijapur, and Bhavanisagar, India, during the 1983 rainy season. All eight were parasitized by *S. asiatica* indicating poor correlation between resistances to these two *Striga* species.

All the *Striga*-resistant varieties we have identified so far are restorers. So we crossed our improved *Striga asiatica* resistant lines with non-restorers to develop *Striga* resistant male-steriles for the production of *Striga* resistant hybrids. The F_2s derived from these crosses were grown in a *Striga*-sick field at Akola where several F_2 plants were selected and test crossed to male

Table 10. Grain yields (kg/ha) and *Striga* reactions (SR) of selected sorghum SAR lines evaluated in *Striga* -sick fields at Akola and Bijapur (checkerboard layout). Plot size 6 m^2 at Bijapur; 5.4 m^2 at Akola, rainy season 1983.

		Akola		Bijapur	
Origin	Pedigree	SR[1]	Grain yield	SR	Grain yield
SAR 1	(555 × 168)-1-1-1	2.1	2070	0.4	1320
SAR 13	(555 × 168)-1-1	1.9	1370	0.5	1300
SAR 16	(555 × 168)-19-2-7-1	0.6	1370	0.3	1080
SAR 2	(555 × 168)-16-1	1.9	1670	0.1	670
SAR 26	(SRN 4841 × SPV 104)-17-1-1	7.2	1600	1.2	460
SAR 9	[SRN 4841 × (WABC × P-3)-3]-7-3-1	3.3	1740	9.4	250
SAR 24	(148 × Framida)-deriv-2-1	4.5	1110	0.7	760
SAR 19	(555 × 168)-23-1-2-1	0.7	1520	0.8	320
SAR 22	(Framida × IS 3922)-7-2-1-2-2-1-5	2.0	1410	0.5	400
Controls					
N 13 (resistant)		1.0	1370	1.5	1110
CSH 5 (susceptible)		73.0	1150	78.0	200
CSH 1(susceptible)		117.8[2]	1360	79.1	430
SE			±203		±234

1. SR of test entries = emerged *Striga* counts as % of CSH 1 control averaged over replications.
2. SR of CSH 1 = emerged *Striga*/m^2 averaged over 60 CSH 1 plots in the checkerboard. Yield of CSH 1 averaged over 60 plots.

steriles to check their nonrestoring reaction. Nonrestoring F_2s will be advanced and backcrossed in the 1984 rainy season.

In collaboration with our Economics Program, we evaluated SAR 1, SAR 2, and SAR 10 in farmers' fields at Aurapalle, Andhra Pradesh, India, using alternate strips of the three resistant lines and CSH 1, a susceptible hybrid. SAR 1 and SAR 2 exhibited good *Striga* resistance under *Striga*-infested conditions. Most farmers liked SAR 1 for its additional higher fodder yields.

Insect Pests

Shoot Fly (*Atherigona soccata*)

Biology. Shoot fly monitoring continued for the seventh consecutive year with fishmeal-baited traps. We replaced square pan, galvanized metal traps with simple plastic traps that gave similar results. The shoot fly population was low during April and May but started to increase with the onset of the monsoon in June, and peaked in August.

Benzaldehyde attracts sorghum shoot fly and seems to be species specific. Its attractiveness to shoot fly was compared with fishmeal in the traps. Although the fishmeal-baited traps captured more shoot flies, the percentage of *A. soccata* was significantly higher in the benzaldehyde-baited traps where *A. soccata* varied from 93.8 to 98.8% compared to 11.3 to 30.0% in the fishmeal-baited traps. In another trial testing different concentrations of benzaldehyde, a 1% concentration was the most attractive to shoot flies. Different attractants (fishmeal, benzaldehyde, ammonium sulphide, and yeast) were used alone or in combination in traps. Traps with fishmeal + benzaldehyde captured significantly more flies and more *A. soccata* (36.5%) than fishmeal alone (28.8%). The proportion of *A. soccata* was significantly higher (40.7%) in traps baited with fishmeal + benzaldehyde + ammonium sulphide + yeast than in traps with other attractants. For convenience the combination of fishmeal + benzaldehyde is now being used to catch *A. soccata* alive for shoot fly resistance screening in cages.

Screening for resistance. Shoot fly screening in cages has been standardized to get higher, more uniform infestations. The trap-collected flies are kept in holding cages in the laboratory for 24 hours. Forty flies per screening cage (1 × 3 m containing 100 plants) left for oviposition for 48 hours gave desired levels of infestation. Egg laying varied from 97.8 to 100.0% on hybrid CSH 1 planted with each set during the entire testing period (October to February). Forty-two less susceptible lines, selected during the previous screenings from 15000 germplasm lines, were tested under no-choice conditions in cages. Although temperatures were too low for fast, normal growth, significant differences were observed in number of eggs laid, % plants with eggs, and % deadheart formation. Nineteen lines (IS Nos. 1082, 1104, 2195, 2205, 2269, 2291, 2309, 2312, 3962, 4646, 4663, 4664, 5072, 5210, 5470, 5480, 5484, 5538, and 18369) recorded significantly fewer deadhearts (52 to 88%) than CSH 1 (99%).

Breeding for resistance. The population resistant to stem and leaf insect pests (shoot fly and stem borer) was again random mated under moderate shoot fly and stem borer infestations during early postrainy season and is ready for S_2 cyclic recurrent selection.

PS 20593, PS 21131, PS 21171, PS 21443, PS 21452, and PS 21453, identified as nonrestoring lines during 1982, were backcrossed twice and are now in their advanced conversion stages (BC3 and BC4).

PS 18601-3, PS 18817-2, PS 18822-4, and PS 19230 shoot fly resistant breeding lines were used as new resistance-donor parents for 133 F_1 single crosses to generate fresh breeding stocks, then advanced to F_2's.

Ninety-seven promising F_2 populations were screened against shoot fly and 1000 individual undamaged plants were selected at ICRISAT Center during the 1983 rainy season. They appeared agronomically better than the first cycle material. However, plant characters such as tallness, late maturity, and compact, small earhead were still associated with shoot fly resistance in most of the selections. Breaking these linkages will require special breeding efforts in the near future.

During 1983 postrainy season, 2285 breeding progenies (1000 F_3's, 298 F_4's, 287 F_5's and 700 F_6's) were tested against shoot fly at ICRISAT Center and 286 progenies (127 F_3's, 43 F_4's, 33 F_5's, and 83 F_6's) showed more resistance than Maldandi (IS 1054), a local standard shoot fly-resistant variety.

The least susceptible lines among advanced progenies are PS 14093, PS 14103, PS 14413, PS 14454, PS 18601-2, PS 18601-3, PS 18817-2, PS 18822-4, PS 18969, PS 19230, PS 19336-1-2, PS 19663, PS 19881-1, PS 21129-2, PS 21171, PS 21217, PS 21269-3, PS 21270, PS 21318, PS 21372-1, PS 19186, PS 19262, PS 19807, PS 19923, PS 20119, and PS 20267.

PS 14093, PS 14413, PS 14454, PS 18601-3, PS 18817-2, PS 1882204, PS 19230, PS 19663, PS 21217, and PS 21318, when tested under good management (including insect control), yielded more than 60% over ICSV 1 (SPV 351) the standard control.

Table 11. Effect of protection levels on stem borer (*Chilo partellus*) infestation and yield loss in sorghum hybrid CSH 1, ICRISAT Center, 1982 and 1983.

Treatment[1]	Deadhearts (%)		Harvestable heads		Grain yield (kg/plot)[2]	
	1982	1983	1982	1983	1982	1983
T_1	10.5	9.5	63.7	102.7	37.0	27.2
T_2	8.2	12.4	67.0	99.3	34.1	23.8
T_3	20.3	21.8	56.7	100.0	29.3	19.7
T_4	49.0	60.1	45.7	34.5	20.5	8.9
T_5	62.2	60.1	33.7	16.5	10.7	4.6
SE	±2.98	±3.79	±2.9	±9.22	±1.26	±1.29
CV (%)	17	23	9	26	8	15

1. T_1 = Carbofuran at sowing and 15, 30, and 45 DAE
T_2 = Carbofuran at sowing and 15, and 30 DAE
T_3 = Carbofuran at sowing, and 15 DAE
T_4 = Carbofuran at sowing
T_5 = Untreated
DAE = days after emergence.
Carbofuran at sowing time applied in soil; after the crop emerged applied in whorl.
2. Plot size: 8 rows 4 m long. Observations taken from middle 4 rows only.

Multiple resistance. PS 18601-3, PS 18817-2, PS 18822-4, and PS 19230 have reasonable agronomic eliteness and multiple resistance to other insects and diseases. PS 18601-3 has additional resistance to downy mildew, leaf rust, and shoot bugs; PS 18817-2 to rust, anthracnose, and shoot bugs; PS 18822-4 to rust, anthracnose, downy mildew, and shoot bugs; and PS 19330 to anthracnose and downy mildew.

Stem Borer (*Chilo partellus*)

Times of infestation in relation to yield. A trial was conducted at Hissar to see the effect of different stem borer infestation times on CSH 1's grain yield during 1982 and 1983. The crop was protected from stem borer infestation at various growth stages by applying 3% carbofuran granules in the soil and in plant whorls. When plants were protected with carbofuran applied at sowing time and 15 days after the crop emerged the % of dead hearts decreased, the number of harvestable heads, and grain yield significantly increased compared to untreated plants (Table 11). Early infestations up to 30 days after crops emerge are critical for deadheart formation and grain yield.

Screening for resistance. We tested 61 lines identified as less susceptible during 1982 under artificial borer infestation at ICRISAT Center and under natural conditions at Hissar. Eleven lines showed less susceptibility (resistance equal to, or better than the best resistant line, IS 2205) at both locations (Table 12). In addition, 2000 fresh germplasm lines were screened at Hissar and 450 selected for further testing.

Mass rearing and field infestation. We further improved mass rearing of stem borer on artificial diet by controlling environmental conditions in the laboratory. To infest the crop uniformly at the right growth stage, a scheme of diet preparation related to time for field infestations is shown in Figure 4; 600 jars of diet are enough to infest 2 ha of sorghum with 5 to 7 larvae per plant. Eggs in the 'black head' stage can be stored at 10°C and 95 to 100% relative humidity for up to 10 days with no significant decrease in their hatchability.

Age of crop at infestation is critical to the development of deadheart symptoms, the main yield-reducing factor. Deadheart formation progressively decreases as infestation is delayed from 14 (74%) to 29 days (6.5%). Shoot flies attacking the stem borer test material pose a problem, particularily in the postrainy season. Carbofuran applied at sowing to control shoot flies adversely affects stem borer infestation (28% deadhearts compared with 67% in the untreated). Endosulfan (0.07%) and fenvalerate (0.005%), sprayed one week before artificial infestation, have no residual effect on stem borer infestation.

Sorghum Midge (*Contarinia sorghicola)*

Population dynamics. Sorghum midge populations were recorded at ICRISAT Center on

Table 12. Incidence of stem borer on less susceptible sorghum lines at Hissar (natural infestation) and ICRISAT Center (artificial infestation).

	Deadhearts (%)	
Pedigree	Hissar	ICRISAT
IS 1044	16.7 (19.2)[1]	20.8 (26.8)[1]
IS 1082	21.4 (27.2)	24.8 (29.1)
IS 2122	20.3 (26.7)	21.0 (27.1)
IS 2123	16.5 (23.8)	19.5 (25.7)
IS 2291	6.7 (12.3)	21.8 (27.5)
IS 5469	9.5 (17.9)	11.0 (19.3)
IS 5538	5.4 (11.0)	31.1 (33.2)
IS 12308	15.2 (23.0)	22.4 (27.3)
IS 13100	4.7 (7.4)	34.1 (35.4)
IS 13674	12.2 (16.9)	29.8 (32.8)
IS 17966	5.5 (8.0)	38.4 (38.2)
Controls		
IS 2205 (resistant)	22.2 (27.8)	41.5 (39.9)
IS 10795 (susceptible)	78.3 (66.9)	80.5 (64.3)
CSH 1 (hybrid)	53.0 (46.8)	57.2 (49.2)
SPV 351 (variety)	96.3 (83.5)	71.6 (58.1)
SE	±(6.76)	±(4.7)
CV (%)	(42)	(23)

1. Figures in parentheses are angular transformations.

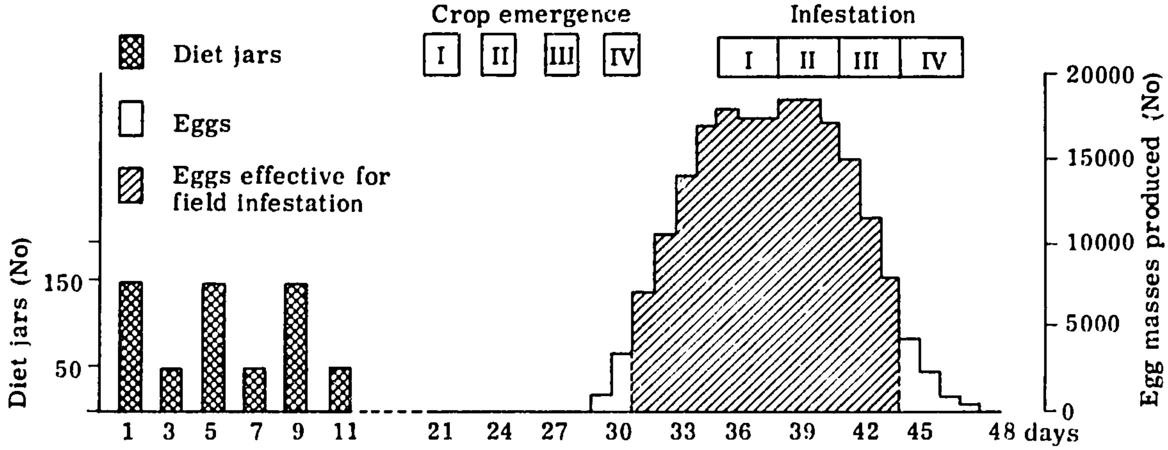


Figure 4. Scheme for mass rearing and field infestation of stem borer, *Chilo partellus*. Alternating 150 and 50 jars of diet starting 21 days before crop emergence will provide effective eggs for infestation of 2 ha from days 31 to 43. Crops emerging on days 21, 24, 27, and 30 will be effectively infested between days 35 and 47.

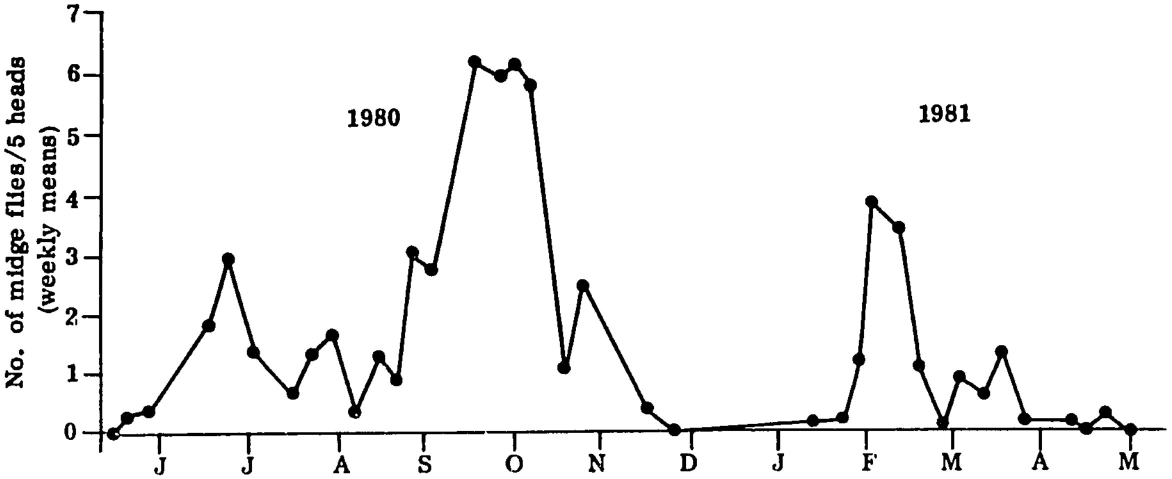


Figure 5. Population dynamics of sorghum midge (*Contarinia sorghicola*) at ICRISAT Center, 1980-81.

cultivar CSH 1 sown at 15-day intervals. Midge flies were counted on five earheads at half-anthesis (Fig. 5). Maximum midge activity occured during mid-October with a smaller peak during February to March. The peaks corresponded with sorghum flowering during the rainy and postrainy seasons. A third peak during July was probably comprised of adults emerging from diapause larvae. Knowing peak dates enables us to adjust planting dates for midge-resistance screening trials.

Screening for resistance. During the 1982 postrainy season, 194 previously-selected germplasm and breeding lines were screened at ICRISAT Center using the headcage technique, and 90 lines were selected as resistant. They were planted in a multilocational trial at ICRISAT Center, Dharwar, and Hissar during the 1983 rainy season. The same 90 lines were tested at ICRISAT Center and Dharwar under no-choice conditions using the headcage technique. Thirty-two lines with low levels of resistance, and 18 moderately resistant lines were selected.

Multilocational testing. An International Sorghum Midge Nursery (ISMN) containing 23 midge-resistant germplasm and breeding lines was sent to collaborators in India, Africa, and America for international testing. Results have not yet been received.

Of 3440 germplasm lines screened at Dharwar under natural pest incidence, 139 were selected for further testing using the headcage technique.

Mechanism of resistance. Studies on the mechanism of resistance to sorghum midge have been conducted the past seasons on 15 entries. Three lines were less susceptible because of nonpreference. Only four cultivars (DJ 6514, 152579C, IS 12573C, TAM 2566) maintained high resistance under no-choice conditions. A study of four resistant and two susceptible cultivars showed that less oviposition (because of floral morphology) and lower larval survival and adult emergence (because of antibiosis) contributed to midge resistance. Floral morphology and antibiosis seem to be the major resistance mechanisms against sorghum midge (Table 13). Of 25 factors studied, short floral parts (such as glume, lema, palea, lodicule, anther, and style), initial faster ovary growth, and high tannin content (except for DJ 6514) are associated with midge resistance (Table 13). Some of these characters can be quantified easily and could be used as screening criteria for selecting lines with high probability of resisting midge damage.

Breeding for resistance. The earhead insect pests (midge and head bugs) population was

Table 13. Factors influencing resistance to sorghum midge (*Contarinia sorghicola*)[1].

				Measurements (length in ocular scale units)[2]							
	Eggs/100	Larvae/100	Adults emerg-	Glume (G)		Lema (L)					Total tan-
Cultivar	florets	florets	ed/head	G_1	G_2	L_1	L_2	Palea	Anther	Style	nins (%)
DJ 6514	50 (7.0)[3]	2 (1.5)	13 (3.5)	139	142	128	71	95	84	46	0.1
AF 28	45 (6.4)	49 (6.9)	24 (4.7)	138	139	130	110	99	90	29	26.3
TAM 2566	14 (3.6)	22 (4.6)	48 (6.9)	122	125	115	99	83	83	40	11.1
IS 15107	13 (3.6)	65 (8.1)	79 (8.9)	156	151	136	107	98	106	46	13.9
Swarna	107(10.4)	106(10.3)	314(17.7)	188	192	163	136	105	108	63	0.4
CSH 1	122(10.9)	138(11.7)	301(17.1)	181	180	149	120	103	120	55	0.4
SE	±(1.9)	±(0.70)	±(1.20)	±3.2	±2.4	±2.4	±2.4	±2.6	±3.1	±2.1	

1. Based on three seasons' experiments.
2. 40 ocular scale units = 1 mm
3. Square root transformations.

tested and random mated under midge infestation at Dharwar during the 1983 rainy season. This will be improved further by recurrent selection after one more cycle of random mating.

PM 6751, PM 7060, PM 7061, and PM 8787-2 were identified as nonrestorers and are being converted into male-steriles for the production of midge-resistant hybrids.

PM 7348, a midge-resistant breeding line, was used as a new resistant donor parent for crossing with 16 different elite parents. Subsequently, its crosses (16 F_1's) were advanced.

Fourteen agronomically promising F_2 populations were screened under midge infestation at Dharwar during 1983 rainy season and 117 midge-free agronomically preferable individual plants were selected. Four hundred fifty-five various generation breeding progenies (210 F_3's, 15 F_4's, 25 F_5's and 205 F_6's) were also screened against midge at Dharwar during 1983 rainy season, from which 65 progenies (45 F_3's and 20 advanced generation progenies) were less damaged and selected.

The best advanced midge-resistant progenies were PM 6751, PM 6932, PM 6981-2, PM 6981-3, PM 7022, PM 7032, PM 7064, PM 7068-1, PM 7068-2, PM 7092, PM 7172-1, PM 7327, PM 7400-1, PM 7400-2, PM 7400-3, PM 7400-4, PM 7494-1, PM 7499, PM 8686-1, PM 10825-1, PM 10825-2, and PM 11344.

PM 11344, a derivative of DJ 6514, was found to have better seed size, grain quality, and leaf disease reaction. The University of Agricultural Sciences (UAS), Dharwar plan to test this line on farmers' fields in midge-endemic areas of Karnataka State during the 1984 rainy season.

Ninety-two advanced breeding lines (F_6's and F_7's) were tested in three different trials to assess their yield potential under good management and insecticide control at ICRISAT Center. The same trials were conducted at Dharwar during the rainy season under high midge infestation pressure. The performance of 12 selected promising lines is shown in Table 14. PM 6751B, PM 7318-2, and PM 7322 yielded well under good management.

PM 7348, PM 7168 and PM 7357 performed well under midge infestations in Argentina, Brazil, and El Salvador where they are being used in national programs. PM 7348 and PM 11344 are also being used in India by the All India Coordinated Sorghum Improvement Project (AICSIP).

Head Bug (*Calocoris angustatus*)

Population dynamics. Head bug populations were recorded at different locations at the ICRISAT farm throughout the year. Head bugs from sorghum heads at milky stage were sampled in polyethelene bags containing a swab of cotton soaked in 2 ml of ethyl acetate. Ten heads were sampled from each of three spots in a field. Maximum head bug activity was observed during September, with another small peak during March. No head bug activity was recorded from May to July (Fig. 6).

Screening for resistance. Of the 2000 germplasm lines screened for head bug resistance during the 1983 rainy season at ICRISAT Center, 15 have been retained for further testing.

The interactions between number of head bugs released in the headcage and the stage of earhead development were studied in 6 cultivars to standardize the headcage technique. Fifteen lines supported lower head bug populations in the headcage test under no-choice conditions. But they were equally susceptible under high natural head bug populations at ICRISAT Center. As yet no line with adequate resistance to head bugs has been identified.

Armyworm (*Mythimna separata*)

Natural enemies. From over 10000 field-collected larvae of *Mythimna separata*, we recorded 6 hymenopteran (*Apanteles reficrus, Disophrys* sp, *Metopius rufus, Campoletis chlorideae, Enicospilus* sp, and *Rogas* sp), 4 dipteran

Table 14. Performance of midge-resistant sorghum breeding lines under good management at ICRISAT Center and midge infestation at Dharwar, rainy season 1983.

Origin	Pedigree	Days to 50% flower	ICRISAT Center		Dharwar		Midge damage[2]
			Good mangnt.[1]	% yield of CSH 6	Midge infestn.[1]	% yield over CSH 6	
PM 6751B	(SC 108-3 × S-Girl-MR 1)-19-1-1	57	3430	81	1610	560	1.5
PM 7060B	(IS 152 × DJ 6514)-1-1-1	59	2340	55	1750	610	1.0
PM 7061B	(IS 152 × DJ 6514)-8-1-1	58	2720	64	2160	750	1.0
PM 7495	(PD 3-1-11 × DJ 6514)-14-3-1	57	2270	53	1770	620	1.0
CSH 6 (hybrid)		54	4250		290		4.5
SE			±150		±189		
CV (%)			±10		±30		
PM 7318-2	(IS 12573C × SC 108)-7-3-5-1	56	4170	92	2120	370	1.5
PM 7322	(IS 12573C × SC 108-4-8)-7-4-3-1	56	3900	87	2170	390	1.5
PM 7390-1	(IS 12673C × PHYR)-15-1-2-1	55	3430	76	2880	510	1.5
PM 7397	(FLR 119 × DJ 6514)-7-1-1-1	57	2460	55	1940	340	1.5
PM 8787-2B	[(FLR 119 × IS 2579C) × Ind-Syn 323-1-3]-2-2-1-2	58	2360	52	2640	470	1.3
CSH 6 (hybrid)		56	4500		560		4.5
SE			±216		±160		
CV (%)			12		17		
PM 7032	(EC 6434 × DJ 6514)-5-1-1-1	60	1820	38	3180	830	0.0
PM 7493	(PD 3-1-11 × DJ 6514)-14-3-1-1	62	2850	60	2290	600	0.5
PM 7526	(Diallel 1457 × DJ 6514)-12-1-1-2	63	2600	55	3220	840	0.0
CSH 6 (hybrid)		56	4740		380		4.5

1. Yield measured in kg/ha.
2. Damage rated on a 1 to 5 scale where 1 = low (<20% damage), 5 = high (80-100% damage).

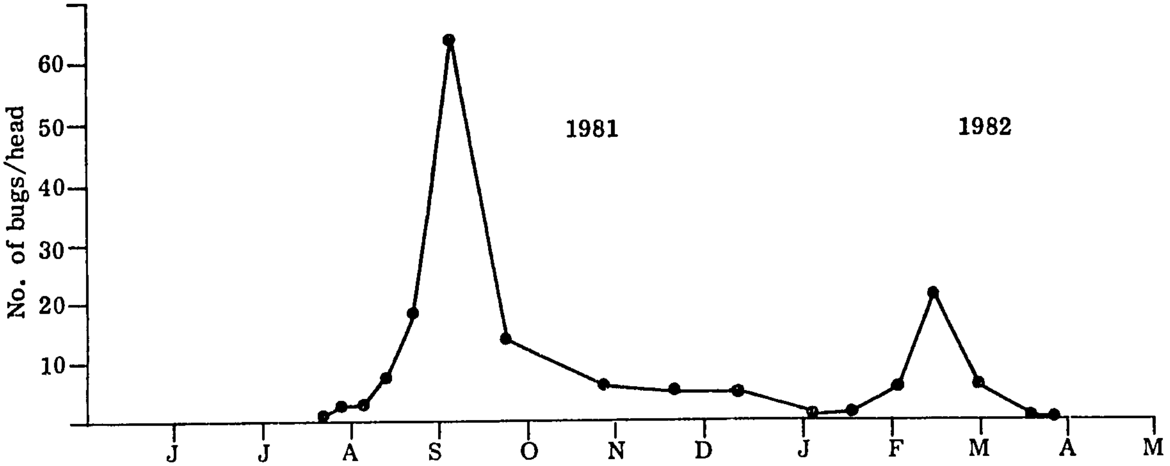


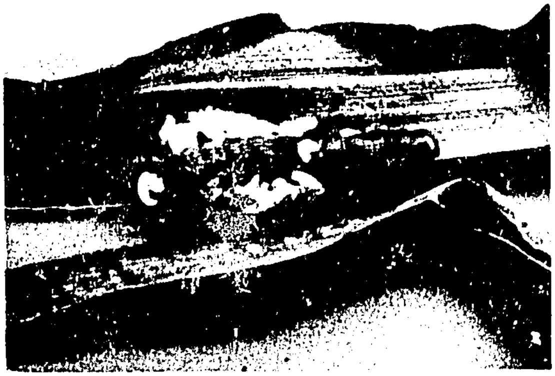
Figure 6. Population dynamics of sorghum head bug (*Calocoris angustatus*) at ICRISAT Center, 1981-82.

(*Carcelia* sp, *Exorista xanthaspis*, *Palexorista solemnis*, and *Megaselia* sp), and 1 nematode parasite. *Anedrallus spinidens* was observed preying on the larvae, which also are attacked by a disease. *Apanteles reficrus*, the most important parasite, has already been successfully used for biological control of armyworm in Australia and New Zealand. At ICRISAT Center larval parasitism increased from June (4.1%) to October (36.3%). Hymenopteran parasites (17.8%) were far more effective than dipteran parasites (3.9%).

Screening for resistance. With the screenhouse screening technique reported last year (ICRISAT Annual Report 1982 p.26), 500 glossy lines were screened for armyworm resistance; 2 of them, IS 353 and IS 777, were selected as less susceptible.

Neem in Pest Control

The antifeedant and growth-inhibiting properties of different parts of neem (*Azadirochta indica*) have been studied in detail in collaboration with the Council of Scientific and Industrial Research (CSIR), Regional Research Laboratories (RRL), Hyderabad. Solvent extracts of the different parts of neem tree were bioassayed, and the ethanolic extract of shade-dried seeds was the most active antifeedant against first and third instar larvae of *M. separata*. Fraction G from the crude ethanolic extract was the most active phagodeterrent under laboratory, greenhouse, and field conditions. Fraction G when purified to fraction M then subjected to column chromatography, resulted in 14 fractions, of which AI-9, AI-10, and AI-11 showed antifeedant and antimoulting properties (Table 15). Fraction AI-10 was the most active; its major component has been designated Vepaol. Fraction AI-8 and AI-12 showed no antifeedant properties but they inhibited larval moulting.



***Mythimna separata* caterpillar attacked by *Apanteles reficrus*, a natural enemy successfully used to control armyworm in Australia and New Zealand. Armyworms feeding on sorghum at ICRISAT Center are parasitized by this hymenoptera.**

Table 15. Effect of 5 neem fractions on the feeding and survival of 3rd instar larvae of *Mythimna separata*[1].

Treatment	Conc. (%)	Damage rating[2]	Unconsumed leaf area (cm^2)	Larval wt (mg)	Mortality (%)	Pupation (%)	No. moths emerged (%)
Neem fraction							
G	0.05	1.2	12.2(3.5)[3]	6.7(2.6)	76	24	16
M	0.05	2.2	10.5(3.2)	9.4(3.0)	76	24	8
AI 9	0.05	1.4	11.5(3.4)	7.4(2.7)	76	24	0
AI 10	0.05	1.3	12.0(3.5)	6.4(2.5)	80	20	0
AI 11	0.05	1.4	11.9(3.4)	6.6(2.5)	76	24	8
Controls							
Acetone	-	4.3	6.8(2.6)	17.4(4.1)	36	64	40
Untreated	-	3.5	7.1(2.6)	16.0(4.0)	36	64	56
SE			±(0.35)	±(0.43)			
CV (%)			±(11)	(14)			

1. Five 3rd instar larvae were confined on treated leaf discs (13.82 cm^2) for 48 hours.
2. Damage rating: 1 = <10% leaf damage, 2 = 11-25%, 3 = 26-40%, 4 = 41-60%, 5 = >60%.
3. Square root transformations in parantheses.

Fraction G tested under field conditions, reduced damage by *Mythimna separata*, *Chilo partellus*, *Myllocerus* sp, and *Calocoris angustatus*. However, it is not effective against *Atherigona soccata*, *Rhopalosiphum maidis*, or *Peregrinus maidis*, probably due to their feeding habits. Weekly sprays of fraction G at 0.1% concentration increased grain yield 30% in sorghum during the 1982-83 postrainy season. We are now attempting to obtain a stable formulation of fraction G for field use against a range of agricultural pests.

Biological Nitrogen Fixation

Nitrogen Balance Studies

In a long-term, nitrogen-balance trial started in 1978, eight sorghum cultivars (Table 16) are grown each year on the same plot with the same rate of added nitrogen. During the 6th year (rainy season 1983) significant differences in total dry-matter yield across the cultivars were observed with different rates of added nitrogen. Highest mean, total plant dry-matter yield of 6860 kg/ha was recorded across cultivars that received 40 kg N/ha. With 20 kg/ N/ha, CSH 5 produced 7490 kg/ha total plant dry-matter yield (Table 16).

Table 16. Total dry-matter yield (kg/ha)[1] of sorghum cultivars in the 6th season of long-term, nitrogen-balance trial, ICRISAT Center, 1983.

	Nitrogen applied (kg/ha)			
Cultivar	0	20	40	Mean
Dobbs	4310	6710	9390	6800
CSH 5	3930	7490	7440	6290
IS 2333	2880	5980	9320	6060
FLR 101	3590	5400	7250	5410
IS 15165	3220	4710	6670	4870
CSV 5	3270	5430	5620	4770
Diallel 642	2780	4780	5640	4400
IS 889	2830	3160	3540	3180
SE		±830		±453
Mean	3350	5460	6860	
SE		±388		
CV (%)		30		

1. Mean of 4 replications. Net area harvested 26.25 m^2/plot.

Nitrogen balance studies with CSH 5 grown in unsterilized Alfisol in pots with three levels of added nitrogen and inoculated with nitrogen-fixing bacteria indicated a positive nitrogen balance due to inoculation (Table 17). The maximum mean nitrogen balance of 331 mg/pot across the nitrogen treatments was observed with *Azospirillum lipoferum* (ICM 1001) inoculation. Addition of 20 kg N/ha equivalent across the inoculation treatments resulted in significantly higher nitrogen balance (297 mg/pot) than with no additional nitrogen (91 mg/pot) or 40 kg N/ha equivalent (3 mg/pot).

^{15}N Isotope-dilution Technique

We did a preliminary pot-culture experiment with six lines of sorghum grown in vermiculite/h sand mixture (1:1 W/W) to explore use of ^{15}N isotope dilution to screen sorghum lines' potential to fix atmospheric nitrogen in the rhizosphere. Tested lines varied significantly in that ability; for one line, IS 801, 27% total plant nitrogen was derived from fixed nitrogen compared with 0% in IS 3003 (Table 18). Considerable dilution of added ^{15}N was observed in all lines so ^{14}N might be from seeds, vermiculite, or contamination of solutions, which can cause dilution. Further experiments are being conducted to find the source of ^{14}N that might dilute the added ^{15}N.

Effect of Mineral Nitrogen on C_2H_2 Reduction

We studied effects of different levels of mineral nitrogen on nitrogenase activity associated with CSH 5 plants by using the tube-culture assay technique developed earlier (ICRISAT Annual Report 1982, pp 86-88). The plants were grown in tubes (25 x 200 mm) filled with 110 g of washed sand, and assayed for C_2H_2 reduction activity 21, 28, and 40 days after sowing. Nitrogenase activity was drastically reduced when the plants were fed nitrogen above 15 ppm. We need to confirm these results with older plants.

Root Exudates and Growth of Nitrogen-fixing Bacteria

Sorghum cultivars differed quantitatively and qualitatively in root exudation. Qualitative differences in soluble exudates were demonstrated by variation in growth and nitrogenase activity of a given bacterial culture in semi-solid N-free synthetic media containing root exudates as the sole organic carbon sources. The *Azospirillum* strains grew well, but the other organisms tested grew poorly with little nitrogenase activity. Amount of exudate showed no correlation with root and/or shoot growth of seedlings grown in axenic liquid culture (Fig.7). Cultivar rankings for associated nitrogenase activity of inoculated *Azospirillum lipoferum* (4ABL) did not corre-

Table 17. Nitrogen balance with sorghum hybrid CSH 5 grown in pots inoculated with nitrogen-fixing bacteria.

Culture	Grain wt. (g/pot)[1]	Total dry matter (TDM) (g/pot)[1]	Nitrogen in TDM (mg/pot)[1]	Net nitrogen balance (mg/pot)[2]
Azospirillum lipoferum (ICM 1001)	13.9	79.9	307	331
Azotobacter chroococcum (ICM 2001)	12.1	75.4	259	226
Napier Bajra Root Extract	14.9	79.9	270	150
Control (noninoculated)	11.6	66.9	223	113
SE	±0.64	±2.52	±8.7	±56.5
CV (%)	17	12	12	

1. Mean of 12 replications. Four plants per replicate pot filled with unsterilized Alfisol in a greenhouse 103 days at 0, 20, and 40 kg N/ha equivalent. Each N level replicated 4 times.
2. Derived from total N/pot in plant dry matter plus rooting medium at harvest minus N in seed, inoculum, fertilizer, and rooting medium at sowing.

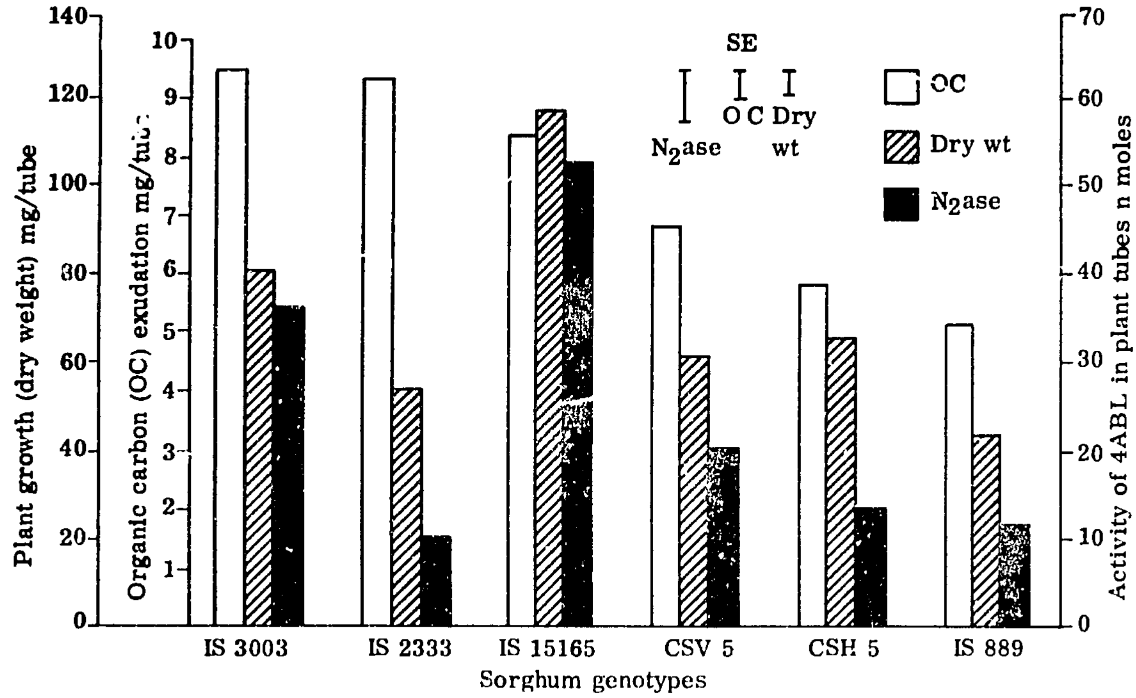


Figure 7. Root exudation, plant growth, and N_2ase activity of *Azospirillum lipoferum* (4ABL) associated with seedlings of 6 sorghum genotypes grown in Fahreus medium in axenic culture. Growth medium changed and organic carbon assayed daily. N_2ase activity estimated on 7th day. (Average of 28 replications.)

Table 18. Isotope dilution estimate of nitrogen fixation associated with sorghum lines[1] (mean of 8 replications).

Line	Shoot weight (g/plant)[1]	Total N (mg/plant)[1]	Atom ^{15}N % excess	% N fixed in relation to IS 3003	N fixed in relation to IS 3003 (mg)
IS 801	35.4	184	1.464	27	49
IS 84	29.4	184	1.549	22	40
CSV 5	26.5	177	1.574	21	37
IS 2980	29.5	160	1.661	17	26
IS 5218	32.9	175	1.742	13	22
IS 3003	36.9	191	1.997	0	0
SE	±1.59	±6.3	±0.0781		
CV (%)	14	10	13		

[1] Single plants in each pot filled with vermiculite were watered with 10 ppm nitrogen as potasium nitrate labelled with ^{15}N (10 atom % excess).

Data from collaborative project with Rothamsted Experimental Station funded by the Overseas Development Administration, UK.

late with amounts of soluble exudate measured. Cultivar rankings also differed from those for growth and activity of *A. lipoferum* (4ABL) in synthetic exudate media.

Plant Improvement

Population Improvement

Recurrent selection. We continued recurrent selection using the S_2 testing selection method in Rs/R, Rs/B, US/R, US/B, and West African Early (WAE) populations and initiated it in the Indian Synthetic population.

We evaluated 397 progenies from Rs/R and 520 from Rs/B populations in an unreplicated nursery at ICRISAT Center. About 196 progenies were selected in each population and advanced to S_2. The selected S_2 progenies were evaluated separately in replicated trials at ICRISAT Center, Bhavanisagar, and Dharwar during the 1983 rainy season. Thirty-five S_2 progenies from Rs/R and 31 from Rs/B were selected and each was recombined to complete the 6th cycle of recurrent selection. In addition, new sources of resistance to midge, *Striga*, and stem borer were incorporated during recombination.

For US/R and US/B populations, 449 and 613 half-sibs, respectively, were grown in unreplicated progeny nurseries during the 1983 rainy season at ICRISAT Center. Approximately 300 plants were selected from US/R and 325 from US/B and advanced to S_1 progenies.

The WAE population has been modified and will be improved for postrainy-season adaptation. S_1 lines were evaluated in replicated nurseries in the postrainy season and advanced to S_2.

For the Indian Synthetic population, 132 S_2 progenies were evaluated in a replicated yield trial at ICRISAT Center, Bhavanisagar, and Dharwar, and 32 S_2 progenies were selected and recombined to complete the first cycle of recurrent selection.

Evaluation of populations. A trial consisting of four cycles of selection for each of the five populations (Table 19) was carried out at three locations in India, four in West Africa, and five in southern and eastern Africa. For the WAE population only three cycles of selection were available so hybrid CSH 5 was included as a control. Due to poor plant growth and drought, yield data were not recorded for the West African locations. Results from the southern and eastern African locations have not yet been received. Grain yield data from three Indian locations (ICRISAT Center, Dharwar, and Bhavanisagar) are shown in Table 19.

Selection gains over cycles for grain yield ranged from 7 to 39% among the five populations. Excessive rains at maturity at ICRISAT Center caused selection gains in the populations to be underestimated. The original population, being early, was harvested before the rains while the improved cycles, which matured later, were caught and suffered reductions in grain yield. In general, improved populations were more uniform, later-maturing, shorter, and had more compact panicles, smaller seeds, and better grain quality. The higher grain yield of improved populations comes mainly from increased grain numbers, more compact panicles, and increased leaf disease resistance.

Development of synthetic varieties. Attempts are in progress to develop synthetic varieties using the most advanced populations of US/R and WAE. We made 200 paired crosses between male-sterile plants and fertile plants within the US/R (C_4) and between US/R (C_4) and WAE (C_3) populations, and evaluated the resulting full-sib and reciprocal full-sib families separately in two trials at ICRISAT Center during the 1983 rainy season. For each trial the families were grouped according to height, maturity, and grain and plant color. From each trial three synthetics (tall, medium, and short) were developed by recombining 5 to 15 of the best entries with similar maturity and tan plant color. These synthetics will be subjected to mass selection for two cycles, then they will be evaluated in multilocational trials to estimate their stability and adaptation compared with commercial varieties and hybrids.

Table 19. Grain yields (kg/ha) of different cycles of sorghum populations evaluated at ICRISAT Center, Dharwar, and Bhavanisagar, India[1], rainy season 1983.

Population	Cycle	ICRISAT Center	Dharwar	Bhavanisagar	Mean	Gain (%)	
						Per cycle	Overall
US/R	C_0	2520	4380	3160	3350		
	C_1	2550	4630	3430	3540	5.4	
	C_3	2250	6360	3870	4160	8.9	
	C_4	2290	5950	4430	4220	1.7	26.0
US/B	C_0	2610	4070	3610	3430		
	C_2	2470	4230	3840	3510	1.2	
	C_3	2260	5280	3660	3730	3.9	
	C_4	2660	4970	4010	3880	3.9	13.0
Rs/R	C_0	2910	4660	3460	3680		
	C_2	2760	5700	3670	4040	5.0	
	C_4	2520	5490	4230	4080	0.5	
	C_5	2440	5910	3470	3940	-3.5	7.1
Rs/B	C_0	2410	4380	2280	3030		
	C_2	2600	4360	4010	3660	10.4	
	C_4	2690	5220	3470	3790	3.6	
	C_5	2590	5470	3580	3880	2.4	28.0
WAE	C_0	1510	3500	3040	2680		
	C_1	1800	4560	4030	3460	29.1	
	C_2	2210	5070	3940	3740	8.0	39.4
CSH 5 (control)		2700	5230	4470	4130		
SE		±141	±318	±297			
CV (%)		10	12	14			

[1] RBD, plot size 18 m^2.

Derived lines. We continued with pedigree selection in our most improved populations. A total of 348 derived lines in various generations were grown during the 1983 rainy season, and 424 individual plant selections were made and advanced to the next generation.

A preliminary varietal trial consisting of 57 advanced population derivatives was conducted at ICRISAT Center, Bhavanisagar and Dharwar. Five lines (E 35-1 × Rs/B 342)-2-2-3-1, [CSV 4 × (GG × 370)]-2-1-4-4, (E 35-1 × US/R 28)-1-1-3-1-2-1, (E 35-1 × US/R 487)-2-2-1-4-1-1-3, and (E 35-1 × US/R 703)-2-1-1-2-2 whose yields equaled that of the best hybrid control were selected for further testing.

Evaluating Advanced Elite Varieties

We evaluated 32 advanced elite varieties along with 1 hybrid and 3 variety controls at ICRISAT Center, Bhavanisagar, and Dharwar. At ICRISAT Center, they were evaluated on Vertisols and Alfisols under low and high fertility and sprayed and unsprayed conditions. Mean days to 50% flower ranged from 67 to 77; plant height (cm) from 178 to 225, both within desirable limits. Yields from Vertisol locations were low but slightly higher than those from low-fertility Alfisol locations at ICRISAT Center, primarily because excessive rains caused waterlogging in Vertisols. ICSV numbers 161, 162, 166, 114, 133, 131, and 138, which performed well across locations, were selected for further testing in international trials. Grain yields of varieties ICSV 162 and 166 equaled those of ICSV 1 (SPV 351) at most locations but were significantly lower than CSH 5 hybrid control.

Female Parents for Hybrids (Male Steriles)

Milo cytoplasm. Eleven of our newly-developed female parents (MA 1 to MA 11) were evaluated for combining ability in a line × tester (11 × 9 hybrids) during the 1983 rainy and postrainy seasons at ICRISAT Center. Average dominance in the hybrids was in the direction of earliness and increased plant height, panicle length, grain number, and yield. General combining ability (GCA) variances were the most predominant for all the characters studied, although significant specific combining ability (SCA) variances were also present. Female parent MA 6 was the best combiner for the rainy season; MA 3, for the postrainy season. Agronomic characteristics of six promising female parents (corresponding B lines) are presented in Table 20.

Backcrossing 2200 A and B pairs in their 5th generation followed by visual scoring for agronomic performance across three locations resulted in selecting 215 A and B pairs, which will be available for testing and distribution during 1985.

From a 15 × 15 diallel cross of the nonrestorer lines derived from our populations and B-lines of commercial male steriles, 474 F_4 progenies were evaluated in the rainy season and 217 plants were advanced to F_5 generation.

Some 212 nonrestorer lines from various populations have been converted into A-lines. They and 30 more A-lines from other projects were evaluated for their performance and combining ability with four testers (A 16003, MR 840, D 71396, and CS 3541). Based on the test, 62 malesteriles were retained for further evaluation and use in the hybridization program. Four lines (SPL 31B, 37B, 112B, and 135B) have shown good resistance to DM.

Nonmilo cytoplasms. Genetic vulnerability of crops is a genuine concern of plant breeders. Genetically uniform material grown over large areas could lead to genetic vulnerability. In sorghum, the commercial hybrids grown throughout the world are based on cytoplasmic-genetic, male steriles of milo-kafir system. We have initiated a research project to assemble and

Table 20. Performance of six new sorghum maintainers (B lines) at three locations in India, 1981 and 1982.

Genotype	Pedigree	Days to 50 % flower[1]	Plant height[1] (cm)	Grain yield (kg/ha) 1981	Grain yield (kg/ha) 1982[2]	Mean
MB 6	[(IS 12645C × 3541) × 9327]-27-2-2-3-2	63	118	4430	4660	4550
MB 5	[(IS 12645C × 3541) × 9327]-27-2-2-6-1	63	119	4100	4730	4370
MB 12	[(SC 108-3 × 148) × 9327]-22-1-2-2-1	63	156	3370	4920	4150
MB 10	(2219B × $UChV_2$)-3-1-1-3-1-1	68	175	2810	4880	3850
MB 3	(2077B × IS 9327)-9-2-8	62	130	3140	4210	3680
MB 9	(Bulk Y × CS 3541)-25-1-1-1	70	135	3020	4140	3580
2219B		59	113	3690	4480	4080
296B		70	140	2530	4860	3700
2077B		70	144	2030	2890	2460

1. Mean over 2 years (1981 and 1982).
2. Mean over 3 locations (ICRISAT Center, Dharwar, and Bhavanisagar).

Coefficient of variation for grain yield ranged from 6 to 25% across locations and years; SE from ±240 to ±670 kg/ha.

Table 22. Mean grain yields (kg/ha) of promising elite sorghum hybrids evaluated at three locations[1] in India, rainy season 1983.

Hybrid	Pedigree	ICRISAT Center HF[2]			ICRISAT Center LF[3]						
		V[4]	A1[4]	A2[4]	AS1[4]	AS2[4]	AUS[4]	VUS[4]	Dharwar	Bhavani-sagar	Mean
ICSH 155	MA 10 × (IS 12611 × SC 108-3)-1-1-3	3020	3300	3670	3780	3590	1940	1720	4590	3890	3300
ICSH 134	2219A × (UChV$_2$ × GG × 370)-4-2-3	2940	2110	4020	4500	3470	3000	1830	4150	3650	3230
ICSH 110	296A × (SC 108-3 × CS 3541)-51-1	3760	2700	2500	3720	2870	2220	1890	4130	3580	3120
ICSH 156	2219A × (UChV$_2$ × GG × 370)-4-2-2	3420	2530	3640	4000	3240	2110	1860	3920	3430	3020
ICSH 164	D$_2$A × [(SPV 105 × (SC 108-4-8 × CS 3541)-1]-14-2	2980	3040	2880	3810	2900	1830	2030	3920	3420	3000
ICSH 162	FLB 8963-2A × (FLR 101 × IS 1082)-4-2	3230	2530	3130	3890	2830	1330	1310	4370	3580	2920
ICSH 132	296A × (SPV 105 × M 36410)-2-2-1	3280	2700	3760	2970	2760	1360	1690	4030	3410	2890
Controls											
ICSV 108	(SC 108-4-8 × CS 3541)-88	2210	2390	3010	2750	2960	860	1280	3700	3030	2470
ICSV 107	(SC 108-3 × CS 3541)-19-1	2580	2010	3140	2830	2120	1830	1250	3250	2790	2400
CSH 9	296A × CS 3541	2390	2730	3940	3420	2810	1940	1060	4300	3560	2930
CSH 5	2077A × CS 3541	3130	2580	3240	3720	2630	2560	580	3870	3280	2770
SE		±369	±316	±354	±415	±369	±312	±205	±316	±269	
CV (%)		22	22	19	21	22	31	24	14	14	

1. RBD, plot size 6 m^2 at ICRISAT Center and 3.6 m^2 at Dharwar and Bhavanisagar.
2. HF = High fertility (128:82:0).
3. LF = Low fertility (40:20:0).
4. V = Vertisol; A1 = Alfisol-1; A2 = Alfisol-2; AS1 = Alfisol sprayed-1; AS2 = Alfisol sprayed-2; AUS = Alfisol unsprayed; VUS = Vertisol unsprayed.

improve the available nonmilo sterility-inducing cytoplasms, hoping to develop commercially-acceptable sorghum hybrids based on nonmilo female parents.

We have contacted several scientists who have worked on nonmilo male-sterility systems and obtained seeds of their stocks.

All the nonmilo cytoplasmic, male-sterile lines we have available were grown for observation and characterization in the 1983 rainy season at ICRISAT Center (Table 21). Three types of sterility expressions were observed: shrivelled anther type (milo-type), nondehiscent anther type, and pollen sterility type.

Hybrid Evaluation

Seventeen hybrids evaluated and selected in 1982 were further evaluated for adaptation and yield stability at ICRISAT Center, Bhavanisagar, and Dharwar, during the 1983 rainy season. We included in the trial two hybrid controls (CSH 5 and CSH 9) and two variety controls [ICSV 1 (SPV 351) and ICSV 108 (SPV 386)]. At ICRISAT Center, they were evaluated in Vertisol and Alfisol under low and high fertility and sprayed and unsprayed conditions. The results of seven hybrids that performed well across locations, together with results of control entries, are presented in Table 22. The yields in Vertisol at ICRISAT Center were lower than in previous years, mainly because of waterlogging. ICSH 155, the highest yielding hybrid, significantly outyielded both CSH 9 and CSH 6 at most locations, which is encouraging because it was produced on our newly bred, male-sterile line MA 10.

About 145 hybrids produced on our six new female parents were evaluated at three locations in five experiments. The results of selected

Table 21. Nonmilo male-sterile sorghum cytoplasms assembled at ICRISAT Center till rainy season 1983.

Origin and pedigree	Source	Remarks
KS 34A	USA	*S. arundinaceum* cytoplasm
KS 35A	USA	*S. arundinaceum* cytoplasm
KS 36A	USA	*S. verticilliflorum* cytoplasm
KS 37A	USA	*S. sudanense* cytoplasm
KS 38A	USA	*S. conspicuum* cytoplasm
KS 39A	USA	*S. niloticum* cytoplasm
IS 1116C	USA	-
IS 12603C	USA	-
IS 7007C	USA	-
IS 12662C	USA	Source of A2 cytoplasm
IS 1256C	USA	-
IS 1112C	USA	Source of A3 cytoplasm
IS 6271C	USA	-
9E-A	USA	Line from Ghana
A2 TAM 428	USA	Improved A line with A2 cytoplasm
A2 TAM 3788	USA	Improved A line with A2 cytoplasm
Isosterile set of IS 84A in VZM, G1, and Maldandi	India	Set has IS 84 nucleus in common
Isosterile set of 148A in VZM, G1, and M 35-1 cytoplasm	India	Set has CS 148 nucleus in common
Isosterile set of CS 3541A in VZM, G1, and M 35-1 cytoplasm	India	Set has CS 3541 nucleus in common
Isosterile set of FR 493A in VZM, G1, and Maldandi cytoplasms	India	Set has FR 493 nucleus in common
Isosterile set of R 16A in VZM, G1, M 35-1, and milo cytoplasm	India	Set has R 16 nucleus in common
Tx 7000A in 9E	USA	Agronomic expression poor at ICRISAT Center
Martin A in 9E	USA	Agronomic expression poor at ICRISAT Center
Tx 399A in 9E	USA	Agronomic expression poor at ICRISAT Center
DD sooner A in 9E	USA	Agronomic expression poor at ICRISAT Center

hybrids are presented in Table 23. Several outyielded the commercial hybrid controls (CSH 1, CSH 5, CSH 6, and CSH 9) and will be contributed for testing in national and international trials. Hybrids produced on MA 6 and MA 10 were less susceptible to grain molds.

Table 23. Grain yields (kg/ha) of selected sorghum hybrids produced from some recently-bred female parents evaluated at three locations in India[1], rainy season 1983.

	Grain yield (kg/ha)			
Hybrid pedigree	ICRISAT Center	Dharwar	Bhavani-sagar	Mean
MA 6 × MR 849	3530	9910	4720	6050
MA 5 × MR 873	3580	9410	4390	5790
MA 6 × MR 836	3670	8480	5180	5780
MA 9 × MR 822	3170	7720	5180	5360
MA 9 × MR 812	3750	6920	4990	5220
CSH 1	2800	6680	3260	4250
SE	±219	±563	±358	
CV (%)	12	12	13	
MA 6 × MR 817	3500	8050	4070	5210
MA 6 × MR 801	3830	7920	3730	5160
MA 6 × MR 806	3360	7850	4120	5110
MA 6 × MR 824	3330	7650	3280	4750
MA 10 × MR 887	3780	7070	2560	4480
CSH 5	3000	7790	4800	5200
SE	±232	±728	±377	
CV (%)	11	18	17	
MA 5 × MR 842	3110	7920	3420	4820
MA 5 × MR 806	3580	6330	4530	4820
MA 5 × M 80954	3000	7520	3310	4610
MA 1 × MR 848	2610	7370	3360	4450
MA 5 × MR 804	3250	7000	2500	4250
CSH 6	2920	6650	3690	4420
SE	±164	±360	±428	
CV (%)	15	9	20	
MA 10 × MR 849	3120	7150	5110	5130
MA 6 × MR 850	2720	7590	4080	4800
MA 5 × MR 890	3570	5700	3540	4270
MA 5 × MR 802	3470	5850	3280	4200
CSH 9	2980	6950	3820	4580
SE	±179	±576	±431	
CV (%)	9	15	18	

1. RBD, 3 replications, plot size varied between sites 4-12 m^2.

In another trial 43 hybrids and 3 controls were evaluated during the 1983 rainy season. Six hybrids had higher grain yields than CSH 9, but only three had desired plant type; all of these hybrids will be retested next year. SPH 232 was the highest-yielding entry (5905 kg/ha compared with 5140 kg by CSH 9).

Eighteen hybrids produced on 2219A, 2077A, and 296A were evaluated along with a commercial hybrid control at three locations in India. SPH 185, SPH 221, and SPH 264 were again the top yielders. Grain yield data of the three hybrids at three locations in India over four consecutive years, presented in Table 24 clearly demonstrate their superiority in yield and stability over CSH 6 and CSH 9.

Food Quality

International Sorghum Food Quality Trials (ISFQT). In 1983 the ISFQT contained 12 white-grain (no subcoat) cultivars with a range of endosperm corneousness. We studied their physicochemical and food quality characteristics. Bulk grain samples of the 12 genotypes (Table 25) were sent to cooperating scientists in Ethiopia, Mali, Mexico, Sudan, Upper Volta, and USA. As yet, data on physicochemical and traditional food quality have only been received from Mali and Mexico.

Physicochemical and nutritional characteristics. Physicochemical and nutritional characteristics of the 12 genotypes were also studied at ICRISAT Center, the results are summarized in Table 25. Grain hardness was estimated by four methods: energy (Joules) required to grind a 10 g sample in a Brabender hardness and structure tester, energy required (arbitrary units) to grind a 5 g sample in an Alpine laboratory universal hammermill, % grains in a sample that floated in a solution of $NaNO_3$ (1.3 specific gravity), and % pearled product recovered ($>1700\mu$) or pearling index, as measured by scarifying 20 g of grain in a Forsberg seed scarifier for 45 sec. Grain hardness measurements made by the four methods

Table 24. Grain yield performance of three elite sorghum hybrids grown at three locations, from rainy seasons 1980 to 1983.

Genotype	Pedigree	Grain yield (kg/ha)[1]				
		1980	1981	1982	1983	Mean
SPH 264	296A × (SC 108-3 × E 35-1)-25-1	–[2]	5630	6940	5090	5890
SPH 221	296A × (SC 108-3 × CS 3541)-27-2-1	5860	5330	7100	5170	5870
SPH 185	2219A × (SC 108-3 × CS 3541)-1-3-1	5010	5910	6190	4520	5410
Controls						
CSH 6	2219A × CS 3541	4420	4490	5420	4090	4600
CSH 9	296A × CS 3541	4310	5190	6710	4580	5200

1. Mean from 3 locations; ICRISAT Center, Dharwar, and Bhavanisagar. Coefficient of variation for grain yield ranged from 6.9 to 24.4%; SE ranged from ±179 to ±576 kg/ha.
2. Entry not included.

Table 25. Physicochemical characteristics of 12 sorghum genotypes[1].

Genotype	Grinding energy[2]		Floaters[3] (%)	Pearling[4] index	Hectoliter weight	Protein (%)	Starch (%)	Amylose (%)
	Brabender mill (J)	Alpine mill (AU)						
E 35-1	81.5	25.5	12	86.4	83.0	10.7	69.5	29.6
S 29	76.9	28.7	9	86.0	82.2	12.4	67.0	30.7
IS 12611	75.2	23.7	16	84.0	80.2	10.9	64.2	29.2
SPH 265	73.9	26.4	3	85.6	83.4	10.5	66.5	27.9
Tetron	77.7	29.3	56	80.3	78.4	11.9	69.0	28.8
Safra	61.7	18.9	63	77.2	79.7	9.9	68.9	29.0
SPH 225	59.1	21.5	42	69.7	80.2	9.9	66.0	29.7
SPV 475	63.4	34.8	28	79.4	82.3	9.6	69.5	29.2
M 35-1	69.0	24.9	9	82.6	83.4	9.7	70.0	31.5
ET 3491	63.7	16.6	46	60.3	78.6	11.6	66.7	27.7
ET 187	68.9	19.3	69	65.6	79.1	11.9	67.8	27.7
P 721	50.0	9.2	90	62.2	70.6	13.5	62.8	19.3
SE	±0.4	±0.5	±3.0	±1.35	±1.01	±0.35	±0.64	±0.88
Mean	68.4	23.2	36.9	76.6	80.1	11.0	67.3	28.3

1. All values reported are means.
2. Estimated in cooperation with the Carlsberg Research Center, Copenhagen.
3. Grains floating in a solution of $NaNO_3$ 1.3 specific gravity.
4. Pearled grain recovered from 20 g by scarification for 45 sec.

correlated well (r values >0.6) so pearling index and % floaters can be reliably used to select breeding lines with hard grains. Variation in percentage of starch and amylose was not significant. Chemical analyses indicated phenolic compounds at low levels in the grain of some cultivars but no tannins.

Effects of milling. The same 12 sorghum samples were milled by village chakki (stone mill),

Villagers at Srinivas Nagar, India, milling sorghum (above) in a power-operated stone mill (chakki). At bottom are the grindstones used in the mill.

laboratory carborundum stone mill, and Udy cyclone mill. The resulting flours were studied for % passing through a 75μ screen, % starch damage, % water retention capacity, volume of water required to make dough, rolling quality of dough, and gel spread. Gel spreads from different sorghum lines are shown in Figure 8. The doughs prepared from the 36 flour samples also were studied with an Instron food testing machine to record the force required to extrude dough in a back extrusion cell.

Milling studies indicated that average particle size of the flour from the village mill was significantly large, with % starch damage and rolling quality as high as those from the carborundum mill. Flour from the Udy mill showed the least starch damage, % water retention capacity, gel spread, and rolling quality. In general, the village mill produced a flour with the highest rolling quality. Statistical analyses indicated that % starch damage, water retention capacity, and rolling quality are highly correlated ($r = >0.8$). Percentage starch damage and % water retention capacity of the flour appeared to strongly influence rolling quality.

Graphs produced by the Instron revealed that extrusion force varied from 19 to 62 kg and correlated with rolling quality ($r = -0.63$). The average extrusion force required to extrude dough made from chakki-milled flour was 31 kg compared with 43 kg for corresponding dough from Udy mill samples. Dough samples with good rolling quality required an extrusion force of 20 to 35 kg.

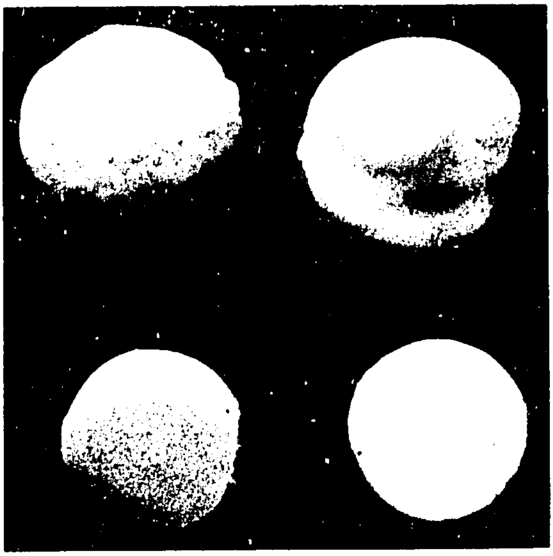


Figure 8. ICRISAT tests the grain quality of the sorghums it develops. The stability of gels under alkaline conditions is important; here are samples with different gel spreads.

Product quality. The food quality factors of the 12 cultivars tested in India, Mali, and Mexico are shown in Table 26. Texture and keeping quality of the *rotis* prepared from soft (P 721) and hard endosperm types (S 29 and SPV 475) were poor but *rotis* prepared from intermediate endosperm (M 35-1, and ET 3491) types were acceptable. Alkali *tô*, prepared from P721, SPH 225, Safra, IS 12611, and E 35-1 was unacceptable. A mini *tô* test at three pH levels showed that the keeping quality of *tô* prepared from some cultivars improved at low pH, although the *tô* was unacceptable at high pH. Stability of the gel (porridge) under alkaline conditions appears to be highly important, while grain texture probably has secondary importance. *Tortilla* quality scores indicate that grains of intermediate and hard texture produced superior *tortillas*.

Inheritance of grain quality characters, 100-grain weight, breaking strength, % floaters, flour particle size, gel spread, and rolling quality were studied in a line × tester mating system during the rainy and postrainy seasons of 1982. All the characters studied were governed mainly by additive gene action. Average dominance was low, in the direction of decreased seed weight, high breaking strength, fewer floaters, large flour particle size, decreased gel spread, and increased rolling quality. The observations indicate partial dominance of grain hardness over softness.

International Cooperation

Our cooperative activity with national programs primarily involves evaluating international adaptation trials and distributing improved breeding lines. Data from our 1982 International Sorghum Variety Adaptation Trials (ISVAT-82) and International Sorghum Hybrid Adapta-

Table 26. Quality of *roti*, alkali *tô*, and *tortilla*[1] made from 12 sorghum genotypes.

				Alkali *tô*[3]						
	Tortilla[2]			Keeping quality				*Roti*[4]		
					Laboratory mini-test					
Genotype	Masa weight	Color[5] ΔE	Acceptability	Taste panel observation	pH 4.6	pH 7	pH 8.4	Taste	Texture	Keeping quality
E35-1	212.3	61.2	2.0	2.2	1.5	1.5	2.5	1.8	1.9	2.5
S 29	208.0	64.3	1.5	1.3	1.3	1.3	1.3	2.1	3.1	2.9
IS12611	225.8	64.4	1.5	2.2	1.8	2.5	2.5	1.9	1.9	2.6
SPH 265	227.5	60.5	2.0	2.2	1.0	1.3	1.0	2.3	1.7	2.5
Tetron	183.8	60.9	2.0	1.2	1.0	1.8	1.3	1.8	2.0	2.1
Safra	202.0	52.6	2.5	3.3	1.0	1.5	3.0	2.0	2.7	2.1
SPH 225	237.8	59.9	2.0	4.0	1.0	1.8	2.0	2.1	2.6	2.6
SPV 475	255.3	60.3	1.5	1.5	1.0	2.0	1.3	2.0	2.6	3.0
M 35-1	223.0	59.1	1.8	1.3	1.3	1.8	1.3	1.9	2.1	2.1
ET 3491	198.8	60.1	2.0	1.2	1.3	1.0	1.5	2.0	2.0	2.5
ET 187	208.3	58.8	2.8	2.0	1.5	1.8	1.8	1.7	2.8	2.1
P 721	252.3	51.6	2.0	4.3	3.3	4.2	5.0	2.9	2.9	3.0
SE	±6.23	±1.11	±0.11	±0.32	±0.18	±0.24	±0.36	±0.08	±0.13	±0.10
Mean	219.5	59.4	1.98	2.19	1.39	1.85	2.02	2.05	2.37	2.5

1. All *roti*, *tô*, and *tortilla* acceptability scores on 1 to 5 scale where 1 = good, 5 = poor.
2. *Tortilla* data provided by ICRISAT, Mexico, all values averaged over 4 replications representing cooking periods.
3. Alkali *tô* data provided by ICRISAT, Mali; observations of taste panelists averaged over 3 replications.
4. *Rotis* scored by 5 taste panelists at ICRISAT Center and Dharwar, values represent averages.
5. *Tortilla* color determined by Hunter laboratory color meter.
$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$ where Δ indicates the difference between observed and standard L, a and b values, respectively.

tion Trials (ISHAT-82) were received too late to be analyzed and reported in our 1982 Annual Report. They are reported below. Data of our ISVAT-83 and ISHAT-83 will be reported next year.

International Sorghum Variety Adapatation Trial (ISVAT-82)

The ISVAT-82 consisted of 24 entries including a local control contributed by the cooperator, 3 varieties (SPV 138, SPV 245, and SPV 346) contributed by AICSIP and 4 controls: varieties ICSV 1 (SPV 351) and ICSV 108 (SPV 386) and hybrids CSH 1 and CSH 5. Mean grain yields of the most promising entries in each geographical region are presented in Table 27. Varieties ICSV 105 and ICSV 112 (SPV 475) gave superior performance in the Indian subcontinent and Southeast Asia; ICSV 102, ICSV 108, and ICSV 110, in southern and eastern Africa; ICSV 1 and ICSV 111, (SPV 472), in West Africa and ICSV 109, ICSV 110 (SPV 387), and ICSV 111, in Central and South America. Variety ICSV 110 produced the highest mean grain yield (4632 kg/ha) across all the geographical regions.

International Sorghum Hybrid Adaptation Trial (ISHAT-82)

ISHAT-82 consisted of 24 entries including a local control contributed by the cooperator and 3 control entries (hybrids CSH 1 and CSH 5 and variety ICSV 1). Mean grain yields of the most

Table 27. Mean grain yields (kg/ha) of top-yielding entries in International Sorghum Variety Adaptation Trial (ISVAT-82), 1982.

Entry	Pedigree	S and SE Asia (6)[1]	S and E Africa (5)	West Africa (2)	Central and S. America (5)	Overall mean (18)
ICSV 110	[(SC 423 × CS 3541) × E 35-1]-2-1	4480	5110	2010	5390	4630
ICSV 111	[(SPV 35 × E 35-1) × CS 3541]-8-1	4190	4290	2540	5600	4430
ICSV 245	(SB 1066 × CS 3541)-SU-14	4080	4680	2190	5380	4400
SPV 346	(SB 1066 × CS 3541)-SU-53	4060	4680	2430	5250	4350
ICSV 112	[IS 12622C × 555) (IS 3612C × 2219B) -5-1 × E 35-1]-5-2	4730	4310	1930	4810	4320
ICSV 109	(IS 12611 × SC 108-3)-1-2-1	3200	4810	2270	5510	4190
SPV 138	CK 60A × SP 1341	4120	4120	2420	4920	4150
ICSV 102	(E 35-1 × Rs/B 394)-1-1-2	3800	5170	1940	4170	4080
ICSV 103	(CSV 4 × GG × 370)-4-4-2	3930	4220	2150	4840	4070
ICSV 105	(CSV 4 × GG × 370)-2-2-2	4710	4370	1750	3220	3870
Controls						
ICSV 108	(SC 108-4-8CS 3541)-88	4150	5410	1880	5140	4520
ICSV 107	(SC 108-3 × CS 3541)-19-1	4010	4380	2530	5170	4270
CSH 5	2277A × CS 3541	3910	4480	2250	5560	4340
CSH 1	CK 60A × IS 84	3210	3110	2400	3990	3310

1. Figures in parentheses indicate number of locations.

	SE range	CV(%) range
Indian subcontinent and Southeast Asia	± 56 to 1018	6 to 36
Southern and eastern Africa	±356 to 754	16 to 38
West Africa	±187 to 425	27 to 28
Central and South America	±328 to 691	14 to 21

Table 28. Mean grain yields (kg/ha) of top yielding entries in the International Sorghum Hybrid Adaptation Trial (ISHAT-82), 1982.

Entry	Pedigree	S and SE Asia (9)[1]	S and E Africa (3)	West Africa (2)	Central and S. America (4)	Overall mean (18)
ICSH 110	296A × (SC 108-3 × CS 3541)-51-1	4710	4830	1930	5150	4520
ICSH 120	296A × (Diallel 475-746)-4-2-1-5	4460	5030	1080	4710	4240
ICSH 106	296A × (SC 108-3 × CS 3541)-20-2-2	4160	5360	1240	4750	4170
ICSH 117	296A × (FLR 101 × IS 1082)-4-3-3	4000	5060	1240	5200	4140
ICSH 109	296A × [(SC 108-3 × E 35-1)-5-1 × CS 3541 Deriv]-2-1-2	4300	5030	1490	4340	4120
ICSH 118	296A × (FLR 101 × CSV 4)-5-1-1-2-1	3880	4990	1390	4900	4010
ICSH 108	296A × (Lulu 5D × 36D) (E 146 × UChV$_2$)-2-5	3730	4870	1110	5370	4000
ICSH 119	296A × (FLR 266 × CSV 4)-4-3-2	4000	3900	1510	4890	3900
ICSH 112	2077A × (SC 108-3 × E 35-1)-25-1	3820	4390	1430	4510	3800
ICSH 105	2219A × [IS 12622C × 555) (IS 3612 × 2219B)-5-1 × E 35-1]-5-2	3730	4660	2440	4000	3800
Controls						
CSV 5	2077A × CS 3541	3390	3640	1230	3810	3280
ICSV 107	(SC 108-3 × CS 3541)-19-1	3260	3960	1450	3400	3210
CSH 1	CK 60A × IS 84	2170	2630	1140	2840	2280

1. Figures in parentheses indicate number of locations.

	SE range	CV(%) range
Indian subcontinent and Southeast Asia	± 47 to 659	11 to 32
Southern and eastern Africa	±477 to 850	11 to 55
West Africa	±127 to 621	36 to 43
Central and South America	±328 to 691	14 to 21

promising entries in each geographical region are presented in Table 28. All our new hybrids significantly outyielded both CSH 1 and CSH 5 in all geographical regions. ICSH 110 was best on the Indian subcontinent and Southeast Asia; ICSH 106, in southern and eastern Africa; ICSH 105, in West Africa; and ICSH 108, in Central and South America. Hybrid ICSH 110 (SPH 296) produced the highest mean grain yield (4522 kg/ha) across all geographical regions.

Contribution to National Programs

Our sorghum variety ICSV 108 (SPV 386) was released by the Government of Zambia as Zambia Sorghum Variety 1 (ZSV 1). SEPON-77 (PR 113-114) has been approved for cultivation by farmers in Nicaragua. In Honduras, a variety named Tortillerio, a selection from CS 3541 developed by AICSIP and supplied to Honduras national program by ICRISAT, has been released for cultivation. In India, variety ICSV 1 (SPV 351) completed four years of testing in AICSIP and two years of minikit tests on farmers' fields with outstanding yield performance (equalling that of hybrid CSH 1). It was recommended for release in India.

Several other varieties are, or will be, in prerelease stage of testing in national programs. In India variety ICSV 108 (SPV 386) was in prerelease minikit tests in 1983, and hybrid SPH 221 was recommended for minikit tests on farmers'

National cooperators examining SAR 1 in minikit test at Ner village, Maharashtra, a *Striga*-endemic area. CSH 6 in the foreground was totally destroyed by *Striga*. Farmers appreciate the increased fodder yields of SAR 1.

fields in 1984. Two varieties with high resistance to *Striga asiatica*, SAR 1 and SAR 2, were extensively tested in *Striga*-endemic areas in seven districts of Maharashtra, India with good results. Seed multiplication of these two varieties is being carried out in that state. Varieties ICSV 108 (S 34) and ICSV 111 (S 35) gave excellent performances in multilocational trials in Nigeria and Cameroon and will be advanced to on-farm testing in 1984.

Several other varieties were tested in multilocational, national trials. In India, our variety ICSV 112 (SPV 475) and four hybrids were evaluated in advanced AICSIP multilocational trials while five varieties and four hybrids were evaluated in preliminary multilocational trials. We also contributed two varieties and one hybrid for evaluation in AICSIP postrainy advanced trials and five varieties and three hybrids for evaluation in ACISIP postrainy preliminary trials.

Four *Striga*-resistant entries were evaluated in the AICSIP *Striga* Resistance Trial for the second successive year. Ten additional resistant varieties were observed in the same trial for the first time. AICSIP has adopted the checkerboard layout (see ICRISAT Annual Report, 1982 p. 34-35).

Several of our varieties are in advanced and preliminary stages of testing in many countries: Botswana, Cameroon, Ethiopia, Kenya, Malawi, Mali, Niger, Nigeria, Senegal, Somalia, Sudan, Tanzania, and Upper Volta in Africa; El Salvador, Guatemala, Honduras, Mexico and Nicaragua in Central America and Argentina and Brazil in South America.

We also distributed many breeding lines to national sorghum research programs for evaluation, selection, and incorporation in national programs.

West Africa

Integrated *Striga* Management: Upper Volta

The *Striga* project in Upper Volta was started in 1979 with financial assistance from the International Development Research Center (IDRC). In its first phase (1979-81), the project's emphasis was on the identification of resistant varieties of sorghum, while in the second phase (1982-Oct 84), the emphasis was broadened to include breeding high-yielding, *Striga*-resistant sorghums with good food quality, and to developing integrated management systems including resistant varieties and some simple agronomic practices. With this objective, agronomy trials were initiated in 1982 and were repeated in 1983 to confirm earlier findings. The results of breeding and agronomy are reported here.

Twenty-five variety trials were conducted in four locations of Upper Volta; the International Sorghum *Striga* Nursery (ISSN) and Advanced Trial were screened in pots inoculated with *Striga*. In general *Striga* infestation was low to moderate in most locations. ISSN materials were sent to Cameroon, Ghana, Kenya, Niger, Nigeria, and Sudan. Data from Upper Volta locations showed that 82S 50 (a selection from a cross between E 35-1 and IS 8785) continued as the highest yielder (1860 kg/ha) followed by the local cultivar (1660 kg/ha), 82S 47 (1570 kg/ha), E 35-1 (1500 kg/ha), and Framida (1490 kg/ha).

Some farmer-managed trials of 82S 50 and 82S 47, which were infested with *Striga*, were analyzed for number of emerged *Striga* plants. Both varieties showed a good level of resistance to *Striga* compared to the local varieties. For three years 82S 50 has produced higher grain yields than E 35-1 and local varieties. During 1983 we extensively tested this cultivar in researcher-managed trials. It was also tested by our economists in farmer-managed trials in a few villages in Upper Volta. The 1983 trials revealed that 82S 50 has better seedling establishment characters under both traditional and improved management conditions that helped produce stable grain yields. It responded to fertilizers significantly more than the local varieties, and its partial photoperiod sensitivity permits flexible planting dates. It has sweet nonsenescent stems, and resists leaf diseases. Its food quality is excellent. It will be considered for preextension trials in Upper Volta in 1984.

Since 1977 we have extensively tested Framida, a brown-grained sorghum identified for *Striga* resistance in Nigeria, at eleven locations. Grain yields of Framida were superior to both N 13 and local varieties every year except 1980, when a local variety produced similar yields. Over all the years Framida's mean grain yield was 1270 kg/ha, 40% more than that of a local variety (910 kg/ha), whereas N 13 produced 680 kg/ha, 25% less than the local variety. Important characters of Framida include its excellent seedling establishment, seedling drought resistance, suitability to intercropping, adaptation to different soil types, partial photoperiod sensitivity, and acceptable qualities for food and local beer. Framida was recommended for preextension trials in 1983 in Upper Volta and introduced into Ghana and Togo. Results of farmer's trials in those three countries are encouraging. It is expected to spread rapidly in northern Guinea Savanna and Guinea Savanna regions of Upper Volta, Togo, and Ghana in the next few years.

Several white-grained selections from crosses involving Framida were screened at the Weed Research Organization (WRO), Oxford, against six *Striga* species using seed samples from Africa and India. Three selections 82S 52, 59, and 79 had resistance to *Striga* equal to Framida's at WRO. We will advance them to researcher-managed trials in 1984. Tetron, a variety from Sudan with *Striga* resistance, will be advanced to researcher-managed trials in 1984.

Six breeding selections, which have been identified as having *Striga* resistance in previous seasons were included in on-farm testing in different villages of Upper Volta to evaluate their grain yield potential. E 35-1 and a local variety were used as controls. The tests were conducted on a total of 18 farmers' fields, 4 in Boromo, 5 in Kamboinsé, 5 in Nakomtenga, and 4 in Yako. Two management systems, traditional (without plowing or fertilizers) and improved (plowed and 37 kg N/ha applied), were compared. Farmers' fields in each village were treated as replications. The results of these trials are presented in Table 29. In all villages, the improved management produced significantly higher yields than the traditional management (1680 vs 700 kg/ha). A selection, 82S 90, from a cross between E 35-1 and Najjad, yielded more than the local variety under both traditional (970 vs 680 kg/ha) and improved managements (2050 vs 1720 kg/ha). It also yielded significantly more than the local variety in Yako and Nakomtenga. Another selection, 82S 104 (from a cross between SEPON 2 and IS 2261), performed better than the local variety under low management (910 vs 680 kg/ha). Both varieties have excellent seedling establishment even under traditional management; 82S 90 and 82S 104 will be advanced to farmer-managed trials in 1984.

Insect Pests: Nigeria

The objectives of the project funded, by SAFGRAD, are to study stem borer and head bug infestation and damage, and to test resistant varieties under Nigerian conditions.

Table 29. Grain yields of selected sorghum cultivars resistant to *Striga* in on-farm testing in four villages of Upper Volta.

	Mean grain yield (kg/ha)									
	Yako		Nakomtenga		Kamboinse		Boromo		Overall mean	
Cultivar	IM[1]	TM[2]	IM	TM	IM	TM	IM	TM	IM	TM
82-S-50	2520	570	1390	360	1080	610	2700	850	1920	600
S 35	2100	640	1240	450	930	450	2160	960	1610	630
82-S-90	3220	1640	1690	680	1170	600	2130	950	2050	970
82-S-79	1560	410	1430	330	1260	660	2120	740	1590	540
E 35-1	2550	470	1510	400	1320	630	2660	1090	2010	650
82-S-59	1180	1000	960	480	860	360	1390	770	1100	650
82-S-104	1480	1340	1160	520	1130	540	2130	1250	1480	910
Local variety	2360	940	1380	470	1190	330	1940	1000	1720	680
Mean (management)	2120	880	1340	460	1120	520	2150	950	1680	700
SE management		±157		±72		±83		±67		
SE varieties		±180		±80		±103		±118		
SE varieties, same management		±255		±113		±146		±166		
SE management, same variety		±285		±128		±160		±170		

1. IM = Improved management (plowing + 37 kg N/ha).
2. TM = Traditional management (no plowing or fertilizers).

Stem Borer (*Busseola fusca*). We investigated the effect time of infestation by *B. fusca* has on grain yield during 1983, using the new method for evaluating stem borer damage.

We marked 500 plants each of sorghum cultivars S 18, K 4, and L 1499 45 days after planting. Then, once a week, until harvest we checked each plant for stem borer infestation. At harvest the number of nodes and internodes bored, visual estimation of damage, and grain weight for each plant were recorded.

The visual damage rating proved efficient (Table 30). The damage rating in the upper half of the stalk provided the highest correlation. Time of infestation and grain weight per head were highly correlated (Table 31). The critical time when stem borer infestation can have a high impact on grain weight per head appears to be near boot formation and flowering. Later infestation does not affect grain yield. The greatest change in yield was observed in the local improved (L 1499) sorghum. This long-season cultivar was being infested three to four weeks before flowering while it was one to two weeks before flowering when the two short-season cul-

Table 30. Correlation coefficient (r), slope (m), and Y-intercept (b) of the regression line between the damage rating and grain weight units per head of indicated sorghum cultivars.

Cultivar		r	m	b
S 18	lower	-0.51	-2.2	70.1
	upper	-0.91	-3.9	76.1
	peduncle	-0.41	-1.7	69.1
K 4	lower	-0.45	-1.7	61.9
	upper	-0.81	-2.3	62.1
	peduncle	-0.22	-0.4	56.0
L 1499	lower	-0.59	-1.4	63.5
	upper	-0.46	-0.7	58.6
	peduncle	-0.75	-2.2	67.2

Table 31. Correlation coefficient (r), slope (m), and Y-intercept (b) of the regression line between time of infestation and grain weight per head for three sorghum cultivars.

Cultivar	r	m	b
S 18	0.99	6.1	22.4
K 4	0.94	4.7	22.7
L 1499	0.95	7.2	-1.7

tivars were infested. Yield reductions were lower with the late infestations. Had the short-season cultivars been infested three to four weeks before flowering, their yield losses might have been higher.

The new visual rating system to score stem borer damage is faster, less expensive, and should be used in the future.

Head bugs (*Camplomma* spp, *Eurystylus* spp). Two sorghum cultivars were sampled weekly from boot formation to harvest to record head bugs (species, adults, and nymphs). Nearby sorghum heads were covered by tergal cloth bags to exclude all head bugs and to determine head bug damage.

Numbers of head bugs collected weekly in 1983 and in 1982 were similar except that more adults and fewer nymphs were collected in 1983. Adult head bugs peaked the 3rd week (303 adults) and bottomed out (7 adults) by the 6th week in S 18 sorghum planted in early July. Number of adults continued to be low on S 18 planted in late July (Table 32). The nymphs peaked twice, in the 5th week in early-planted sorghum and in the 6th week in late-planted sorghum.

The species composition on S 18 in 1983 was similar to that in 1982: *Camplomma* sp 1 (23%), *Camplomma* sp 2 (6%), *Eurystylus* (63%), and two unidentified species of the 14 mentioned in 1982 (ICRISAT Annual Report, 1982 p.370) were the most abundant bugs collected. Both *Camplomma* spp occurred early as heads emerged from the boot and peaked in the 2nd and 3rd weeks. *Camplomma* sp 1 maintained high numbers from the 2nd to 5th weeks in 1983 compared with a peak in the 3rd week and a drop in the 4th week in 1982. *Eurystylus* spp peaked quickly in 1983 and by the 3rd week accounted for 59% of all adults collected. They remained high until the 5th week when the level dropped; it remained low in the late-planted sorghum. The same general pattern was observed in 1982 when *Eurystylus* numbers were high from the 3rd to 6th week and peaked the 5th week (Table 32).

The main difference between 1982 and 1983 occurs in sp 1 and sp 2. These two species accounted for 35% of all adults in 1982 but only 6% in 1983.

Both adult and nymph head bug numbers peaked the 6th week after heads emerged on the long-season, open head L 1499, which was planted in early July. Numbers of adult and nymph head bugs collected from open head sorghum nearly equalled the number collected on compact head sorghum during the same period (Table 33).

Numbers of head bugs at Kano were lower than at Samaru but they showed the same general pattern, adults peaking during the 4th week and nymphs the 5th. The number of head bugs collected from S 18 was higher than from K4 (Table 34).

The species composition at Kano was similar to that at Samaru but the abundance of various species differed widely. *Camplomma* sp 1 (36% on S 18 and 47% on K 4), *Eurystylus* (28%), and *Camplomma* sp 2 (24% on S 18 and 20% on K 4) were the commonest.

The various beetles found in high numbers in 1982, especially the weevils (*Myllocerus subfasciatus*), were nearly absent in 1983. The low rainfall and extended drought could have reduced their abundance.

Insect Pest Nurseries. In 1983 the International Sorghum Shoot Fly Nursery (ISSFN), The International Sorghum Midge Nursery (ISMN), and Sorghum Breeding Sorghum Stem Borer Nursery (SBSSBN) were conducted at Samaru.

Breeding: Mali

Our objectives are to obtain homogenous high yield potential breeding lines and varieties with

Table 32. Weekly distribution of head bug species collected from sorghum cultivar S 18 at Samaru, Nigeria, 1982 and 1983.

	Species (adult)						
Date	*Camplomma* sp 1	*Camplomma* sp 2	*Eurystylus* sp	U sp 1	U sp 2	Total adults[1]	Total nymphs[2]
1982							
September							
9	1	7	0	3	9	28	2
16	7	12	5	4	15	53	3
24	30	18	25	11	10	106	18
October							
1	10	3	23	14	9	83	243
8	2	5	58	20	35	136	725
14	4	2	38	23	11	92	343
19	4	3	8	15	4	38	97
Total	58	50	157	90	93	536	1421
1983							
September							
23	5	1	0	0	0	8	0
30	33	11	7	2	3	64	2
October							
7	48	15	233	3	13	303	180
14	18	9	122	3	18	159	393
21	27	9	69	0	0	109	439
28	16	2	7	2	1	27	161
November							
4	6	0	11	0	0	21	61
11	5	0	4	0	0	15	161
18	3	0	7	0	0	16	303
25	5	0	1	0	0	7	35
December							
2	0	0	1	0	0	1	1
Total	166	47	462	10	35	730	1736

1. Includes other unidentified species not shown. 2. Nymphs for all species observed.
U = Unidentified.

characteristics which will assure adaptation to West African field conditions and food systems.

In 1983 we advanced 170 F_6 lines and 490 F_4 lines from our recurrent selection population. Our most recent F_4 progeny include several short sorghum lines that combine many local Guineense sorghums' desirable traits, including leaf disease tolerance, charcoal rot resistance, hard seed, and long, involute glumes. Experimental lines that performed well at four Malian locations are being recombined in the 1983 winter nursery. The best F_5 and F_6 progenies will be yield tested in 1984.

At Bema in northern Mali, where drought killed local sorghums, several of our early-maturing breeding lines (derived from populations) matured normally with only 280 mm of rainfall. We will increase those lines for yield tests next season.

We obtained a series of F_5 sister B lines from

Table 33. Weekly distribution of head bug species collected from sorghum cultivar L 1499 at Samaru, Nigeria, 1983.

	Species (adult)						
Date	*Camplomma* sp 1	*Camplomma* sp 2	*Eurystylus* sp	U sp 1	U sp 2	Total adults[1]	Total nymphs[2]
October							
14	1	1	0	0	0	3	2
21	1	1	0	0	0	5	5
28	1	1	3	2	0	6	14
November							
4	3	0	6	0	0	14	44
11	3	0	3	0	0	11	436
18	5	0	79	0	0	93	637
25	7	0	8	0	0	20	112
December							
2	0	0	1	0	0	3	2
Total	21	3	100	2	0	155	1252

1. Includes other unidentified species not shown. 2. Nymphs for all species observed.
U = Unidentified.

Table 34. Weekly distribution of head bug species collected from sorghum cultivars S 18 and K 4 at Kano, Nigeria, 1983.

	Species (adult)							
Date	*Camplomma* sp 1	*Camplomma* sp 2	*Eurystylus* sp	U sp 1	U sp 2	U sp 5	Total adults[1]	Total nymphs[2]
S 18								
September								
27	2	4	0	0	–[3]	10	18	1
October								
4	18	5	5	1	3	16	47	2
11	31	2	16	0	0	22	76	196
19	13	1	24	0	0	5	46	348
23	25	3	23	0	0	0	59	325
Total	89	15	68	1	3	59	246	872
K 4								
September								
27	3	1	1	0	0	11	16	0
October								
4	10	4	7	0	0	7	29	5
11	24	2	17	0	0	14	44	144
19	10	2	15	0	0	1	33	207
23	32	1	6	0	0	1	45	104
Total	79	10	46	0	0	34	167	460

1. Includes other unidentified species not shown. 2. Nymphs for all species observed. 3. Data not recorded.
U = Unidentified.

the cross between the short American B 623 and the tall, local landrace CSM 37. F_5 progeny selections combine the short stature, high seed number, and plant vigor of B 623 and the open panicle, hard seed, and long glumes of the Malian parent. Lateness (80 days to flower) of the new B lines is promising for F_1 hybrids in Mali's major sorghum-producing zones. The new B lines are being sterilized as A lines and crossed onto our new B line population.

We devised a simple method to find the degree of panicle openness required to escape molds and insects. The hardness and weight of grains on the outside of panicles are compared with that of grains on the inside of panicles. Grains on the inside of compact panicles weigh significantly less and are softer than the grains exposed to the outside. The method enables us to rapidly screen large numbers of progeny that segregate by degree of panicle openness.

Breeding: Upper Volta

The objectives of sorghum improvement in Upper Volta are to develop cultivars that mature in 140, 120, or 100 days to match variability in rainfall, with plant height of about 2m, juicy stalk, nonsescencence, good panicle exertion, semi-compact panicle, good grain quality, and resistance to drought, diseases (grain mold, leaf diseases, and stalk rot), and insects (aphids and sorghum midge). Additional emphasis is now given to early seedling vigor and establishment under poor tillage.

Rainfall during 1983 was sparse throughout the country and yields were low. Kamboinse's 663 mm rainfall was 95 mm below average. A drought lasting two weeks during preheading was followed by another drought during grain filling.

Adoption of E 35-1. We have been cooperating with the Centre d'Experimentatio du Riz et Cultures Irrigues (CERCI)/FAO project since 1976. We provided more than 100 promising early- and medium-maturing lines for testing under irrigation in October/November after rainy-season rice is harvested. Based on several years of on-farm tests, E 35-1 was recommended for extension under irrigated conditions in 1983. Its yields have averaged 3.5 t/ha. SPV 35 also was similarly recommended. Comparative yield data are presented in Table 35.

Table 35. Comparative grain yield (kg/ha) of sorghum cultivars E 35-1 and S 29 in farmer-managed plots, Linoghin Region, Upper Volta, 1983.

Farmer	E 35-1	S 29	Superiority over S 29 (%)
1	1815	890	204
2	1270	1200	106
3	2077	1475	141
4	1462	1219	120
5	1180	837	141
6	1944	1644	118
7	1975	1587	124
8	1426	1196	119
9	2184	1681	127
10	1510	1177	128
11	1679	1290	130
12	1975	1587	124
13	1426	1196	119
14	2134	1581	127
15	1510	1177	128
Mean	1704	1316	129

E 35-1 plants remain nonsenescent at grain maturity; the stalks are juicy and sweet. In Upper Volta efforts are under way to use E 35-1 not only for grain harvest but also for gashol production under supplementary irrigation during the rainy season and under full irrigation during the dry season.

Pedigree selection. Farmers will adopt improved varieties only if new varieties possess the useful traits of local varieties, e.g., superior seedling establishment, drought tolerance, and high photosensitivity. Therefore, we started a crossing program in 1978 involving high-yielding, management-responsive, short- and medium-maturiting introductions and local varieties from Upper Volta and other countries in West Africa. Following pedigree selection procedures, we identified 396 lines comprising the three maturities—100, 120, and 140 days.

We grouped the 396 lines into 18 trials, each containing 25 entries including 3 known controls (E 35-1, Framida, and SPV 35). Each trial was laid out in a 5 × 5 lattice design with six replications. To simulate farmers' conditions, land was harrowed approximately 5 cm deep but not plowed, and NPK fertilizer (60:40:15) was applied.

Despite the serious drought, several promising lines were identified, including CE 90 × NES 1077 and 153 BK × SB 722/67-2 in early-maturing, VS 702 × CSV 4 in medium-maturing, and NES 1077 × 1000 and 926 × 1089 in late-maturing lines. Selected entries will be further tested in multilocational trials under good management in 1984.

During 1983 we selected 367 $F_2BC_1F_2$ plants from 78 progenies for pedigree selection. Also, 89 $F_2BC_1F_2$ plants were selected for backcrossing to corresponding parents. The F_2 of BC_2 generation will be selected in 1984.

Screening nurseries. We grew screening nurseries to evaluate elite material for resistance to grain molds, shoot fly (*Atherigona soccata*) and midge (*Contarinia sorghicola*). The nurseries were planted at Farako-Bâ, near Bobo-Dioulasso. The cooperation and guidance of the national entomologist in conducting the trials was invaluable.

The most promising entries (scores 1 and 2) for grain mold resistance were IS 8848, IS 9353, IS 9487, IS10892, IS 14332, IS 14375, IS 14380, IS 14384, IS 14387, IS 14388, and IS 17141.

In the sorghum shoot fly nursery entries 2% or less damaged were IS 5470, IS 5566, IS 22121, PS 14454, PS 18601-3, PS 18822-4, PS 19230, PS 19794, PS 212-4, PS 21318, PS 14094, PS 18693, PS 19434-2, PS 19795, PS 20119, and PS 20268.

The best entries in the midge nursery were PM 7422-2PC82R, PM 7061PC82R, PM 7495PC82R, PM 6751, PM 7060, PM 7061, PM 7422-2, and PM 8590.

Inspite of the below-average rainfall in Farako-Bâ in 1983 (755 mm as compared to the normal 1000 mm), it was still possible to discriminate between entries for all three traits.

International and regional trials. In 1983 we planted two regional trials in Kamboinsé—the West African Regional Observation Nursery (WARON) and the West African Regional Trial (WART). We also conducted three ICRISAT Center trials—International Sorghum Variety Adaptation Trial (ISVAT-83), International Sorghum Hybrid Adaptation Trial (ISHAT-83), and International Sorghum Population Cross Trial (PCT). Despite serious drought, we identified several promising lines.

Eastern Africa

Cooperative Trials

Sorghum workers of the Eastern Africa Region in meetings (17 to 21 October 1982) in Ethiopia agreed to have the Semi-Arid Food Grains Research and Development (SAFGRAD) Coordinator organize regional sorghum variety trials with entries contributed by the national programs in the region for each of four major agroecological zones: high, intermediate, and low elevations, and very dry lowlands. Four regional trials (Table 36) were organized and distributed to 50 locations in the region.

Trials in some locations in Kenya, Sudan, and Ethiopia were evaluated visually but full data are not yet available. At Katumani, Kenya, Gharib red and Gharib white were used in crossings with local selections. At Wad Medani, maturity, adaptation, grain quality, and overall agronomic eliteness varied widely in the Low Elevation Trial.

Germplasm: Introduction, Screening, and Use

To broaden the sorghum germplasm base used by workers in eastern and southern Africa a wide range of sorghum material, comprising some 1500 entries, including R, A, and B lines and populations, drought and *Striga*-resistant lines, advanced breeding lines, and elite varieties from African, American, and ICRISAT breeding programs were introduced in 1983. This material is being evaluated at Katumani, during the 1983 short rains and the most promising entries will

Table 36. Entries contributed for Eastern Africa Cooperative Regional Sorghum Trials, 1983.

Contributing country	High elevation, >1800 mm	Intermediate lowlands, 1500-1888 mm	Low elevation, <1500 mm	Very dry lowlands[1]	Total
Burundi	SVR 157	SVR 8	5DX 160		3
Ethiopia	ETS 2752 Alemaya 70	ESIP 12 Bakomash 80	Gambella 1107 Melkamash 79	77T1-23	7
Kenya	E 1291 BJ 28 × BG 19	2K × 17	76T1-23 IS 8595	Mukerji DB 822	7
Rwanda	BM 10 BM 27	SVR 157 Susa	Badege Urimimbi		7
Tanzania			Tegemeo	5D × 135/ 13/1/3/1	3
Uganda			Serena Seredo E 525 HT 2K × 17/B/1	3K × 72/1 3K × 71/1 3K × 73/4 3K × 76/5	8
Yemen AR	Kadasi Hamra Hujariya	Buraihi	Tajarib SEPON 9-1	Gharib red Gharib white	8
Total entries	10	8	15	10	

1. <500 mm rainfall, <1500 m elevation.

be advanced and seeds made available to interested national programs of the region in 1984.

Latin America and the Caribbean

Regional Agronomy Program

ICRISAT has a sorghum breeder and an agronomist working at the headquarters of Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in Mexico on sorghum research in Latin America, in close cooperation with the Instituto Nacional de Investigaciones Agricolas (INIA). The primary breeding objective is to develop high-altitude, cold-tolerant sorghum varieties with good grain quality for *tortillas*, snacks, cookies, and bread, using sorghum dough mixed with other cereals. A secondary objective is to improve genetic material adapted to low and intermediate elevations in Latin America.

ICRISAT scientists work closely with INTSORMIL (USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet) Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE), Centro Internacional de Agricultura Tropical (CIAT), and national programs of the region. Strong cooperative links between these institutions help avoid duplicated effort.

Agronomy research began this year with the following objectives:

1. To field test new sorghum cultivars developed in ICRISAT's regional programs and in national programs, and to identify genotypes useful for food and animal feed, with tolerance to drought and cold, and resistance to diseases and insects. Priority is given to hybrids and varieties which do well at high altitudes (1500 to 2500 m) and low temperatures (below 17°C).

2. To test performance of genotypes in farmers' fields and develop cropping systems useful on small farms.
3. To transfer improved technology systems developed through research to subsistence farmers.

In the Mexican highlands five varieties were identified as early and drought-tolerant enough for further evaluation. Yields of 3 to 5 t/ha were obtained in dryland farmers' fields under low inputs.

Intercropping experiments involving plant density and fertilizer N and P levels are conducted at 22 sites in farmers' fields. In regional sorghum-based cropping systems we are studying three traditional maize and sorghum systems, and one improved system in a uniform experiment across El Salvador, Guatemala, Haiti, Honduras, Mexico, and Nicaragua.

During the year two scientists were trained in sorghum production, one each from Guatemala and Haiti. We cooperated with national programs dealing with sorghum in 10 countries, and explained ICRISAT's role at regional conferences in Panama at the Programa Cooperativo Centro Americano para el Mejoramienta de Cultivos Alimenticios (PCCMCA) and Mexico (Workshop on Production and Quality of Sorghum, Irapuato), and at the 2nd Annual Meeting of the Commision Latinoamericano de Investigadores en Sorgho (CLAIS) in Honduras.

Breeding. Intensive breeding efforts are needed to meet increased demands from the Caribbean and South and Central American countries for new sorghums adapted to highland and lowland tropics. In addition to evolving and introducing new varieties, the program is now geared to developing good parents to produce hybrids for both highlands and lowlands.

We contribute material annually to the Latin American Rainfed Sorghum Yield Trial (LARSYT) for testing across locations in marginal areas in Latin America.

We also screen food-type sorghums in our laboratory, identify different food products prepared from sorghum in Central America, and try to create an awareness of sorghum grain as human food in Central America where it is used primarily as animal feed.

Achievements. Through yield trials, Latin American Elite Variety Sorghum Yield Trial (LAEVSYT) and Latin American Drought Tolerant Sorghum Yield Trial (LADTSYT) and requests for seeds, ICRISAT varieties are in use in breeding programs in El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, and Venezuela. There are two or more varieties in the production stage in the following countries: Costa Rica, ISIAP Dorado; El Salvador, ISIAP Dorado and San Miguel 1 (Association); Guatemala, M-90386; Haiti, M 62641 (SC 108 × CS 3541)E 15-5 and (IS 12611 × SC 108)-4-4-8; Mexico, (IS 12611 × SC 108-3)-7-2-1, (IS 12611 × SC 108)-4-4-8, D 71205, and ISIAP Dorado; Nicaragua, SEPON 77; Panama, ISIAP Dorado; and Venezuela, SEPON 77, (T × 954052 × CS 3541)-15-6, and M 35544(SC 108-3 × CS 3541)-29-1.

A 1983 yield trial with genotypes that differ in susceptibility to fall armyworm *Spodoptera frugiperda* and stalk borer *Diatraea* sp indicated that the screening method we used identified genetic differences in sorghum reactions to those two insects. Continued progress toward resistant varieties through screening and recombination is thus possible.

We have identified several families with tolerance to armyworm but none for stalk borer. However, the best glossy lines from ICRISAT Center included several families with seedling stage tolerance that filled grain normally. Work with those families is continuing. Sorghum genotypes identified as most tolerant to fall armyworm and stalk borer are M 66152(NPEC 64735 × E 35-1)-7, TAM 428, 88-4 Poza Rica, 787-3, and 896-1.

We evolved a screening method that helps us identify varieties and hybrids with drought tolerance. Hybrids selected as tolerant yielded much more than their parents in two years of testing under drought stress.

INIA's close cooperation with ICRISAT speeds up identification and production of sorghum genotypes for human consumption. INIA's grain laboratory tested several of ICRISAT's new food-type varieties to identify the best genotypes for food qualities. Several have been identified for use in making *tortillas.*

Workshops, Conferences, and Seminars

Consultative Group Discussion on Research Needs and Strategies for Control of Sorghum Root and Stalk Rot Diseases

We sponsored jointly with USAID's Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL) a group discussion at Bellagio, Italy, 27 November-2 December. It was attended by 27 participants who assessed current knowledge, available control measures, and constraints to research, and determined future research strategy. Of the seven basic disease problems considered, the most important were fusarium root and stalk disease, charcoal rot, and anthracnose stalk rot. Others discussed in less detail were pythium root rot and seedling disease, periconia root rot, acremonium wilt, and root rots associated with nematodes. Detailed recommendations are contained in the proceedings, obtainable from Information Services, ICRISAT.

Sorghum Field Days

Forty sorghum scientists, including breeders, physiologists, and agronomists from various Indian agricultural universities and research stations, participated in field days at ICRISAT Center, 26-28 September. This provided an excellent opportunity for the scientists to see and discuss ICRISAT's work. The visitors also selected ICRISAT material for use in their research programs.

Second Workshop of the Eastern Africa Sorghum and Millet Improvement Network

One of the main objectives of the ICRISAT/SAFGRAD program in eastern Africa is streng-

Visiting sorghum scientists examine the growing crop and discuss work with ICRISAT scientists.

thening the sorghum and millet research network in the region. To this end annual workshops for active research workers in the region were organized in 1982 and 1983. National programs of Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda, Yemen AR, and Yemen PDR are participating in the workshops and have agreed to take part in the regional research network. The second workshop held in Rwanda, was attended by 30 participants. Results of the 1982 crop season were discussed with emphasis on those of Rwanda, the host country. The proceedings are in press.

Looking Ahead

Physical stresses. We will continue to develop techniques to screen large numbers of lines for resistance to severe environmental stress by using germplasm lines from a wide range of taxonomic groups, geographical regions, and climates. We will pay attention to the underlying mechanisms associated with resistance by encouraging physiologists outside ICRISAT to do research on observed resistant and susceptible sources. An ODA-funded group from the Welsh Plant Breeding Station, Aberystwyth, UK, is working on problems of high temperature in crop establishment. Other projects are to be placed with scientists in the UK, USA, and Australia. In collaboration with entomologists and pathologists, we are also looking into the influence of such factors as depth of planting and diseases and insects on crop establishment.

Biotic stresses. Our research on grain molds will concentrate on elucidating infection and colonization processes, the nature of resistance, and increasing resistance in white-grain sorghums. A major interdisciplinary effort involving pathologists and physiologists will be made to study the host parasite-environment interaction in root and stalk rot diseases, based on recommendations made at the Consultative Group Discussion on Research Needs and Strategies for Sorghum Root and Stalk Rot Diseases jointly sponsored by INTSORMIL and ICRISAT in November 1983 (see Workshops, Conferences, and Seminars). Research on downy mildew will concentrate on the biology of seed infection, role of seed-borne inoculum and the nature of resistance. Research on leaf diseases will concentrate on anthracnose with emphasis on physiologic races, the role of seed-borne inoculum, and the nature of resistance.

We will increase the grain yield potential of our *Striga*-resistant breeding lines and incorporate resistance to diseases and insects. We will give priority to developing female parents resistant to *Striga* for the production of *Striga*-resistant hybrids.

We will continue to concentrate on the identification of resistant sources for shoot fly, stem borer, and midge and determination of the resistance mechanisms involved. We will intensify our search for lower levels of susceptibility to head bugs as well as looking into alternative control methods. Our studies on neem extract will continue with the main objective of identifying an easily-obtainable and formulated neem extract for insect control in farmers' fields.

Nitrogen fixation. We will use ^{15}N to study variation between lines in fixing atmospheric nitrogen and utilizing the fixed nitrogen for plant growth. With further experimentation, we will standardize and use the ^{15}N isotope dilution technique for screening lines for their potential to stimulate rhizosphere nitrogen fixation. We will also study, in field trials, the response of different cultivars to inoculation with nitrogen-fixing bacteria. The effects of different levels of mineral nitrogen on the nitrogenase activity of older plants will also be studied.

Plant improvement. Priority will be given to developing multifactor resistant B and R populations for the rainy season, and a BR population for the postrainy season. Sources of resistance to important characters in the geographical regions of the SAT will be incorporated into the three populations and improved by recurrent selection for multiple resistances in agronomically elite backgrounds.

We will initiate a program to convert landraces known to posses valuable traits and incorporate genetic male sterility into the converted material to accelerate its use in breeding programs.

We will continue to emphasize the development of diverse female parents with milo cytoplasm and increase our emphasis on improving and identifying suitable nonmilo, male-sterile lines to produce commercial sorghum hybrids.

Publications

Institute Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics.) 1983. Proceedings of the Second International Workshop on *Striga*, 5-8 Oct 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru,A.P. 502 324, India: ICRISAT. 129 pp.

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PEARL MILLET

Contents

Physical Stresses 67
Cultivar Performance under Low Fertility 67
Nitrogen Uptake and Use 67
Genotype × Fertility Interactions 68
Selection under Low Fertility 68
Crop Establishment 69
Seedling Emergence through Soil Crust 69
Drought Screening 71

Biotic Stresses 73
Diseases 73
Downy Mildew (*Sclerospora graminicola*) 73
Ergot (*Claviceps fusiformis*) 77
Smut (*Tolyposporium penicillariae*) 80
Rust (*Puccinia penniseti*) 83
Multiple Disease Resistance 84
Insect Pests 84
Armyworm (*Mythimna separata*) 85
Heliothis armigera 85

Microbial Associations 85
Biological Nitrogen Fixation 85
Relationship between Assay Methods of Measuring Nitrogenase Activity 85
Nitrogen Balance Studies 85
^{15}N Isotope-Dilution Technique 86
Nitrogen-fixing Bacteria 86
Responses to Inoculation with Nitrogen-fixing Bacteria 87
Variation in Ex-Bornu for Stimulating Rhizosphere Nitrogenase Activity 89
Mycorrhiza 89
Phosphorous Nutrition 89
Genotype-Dependant Colonization 89
Genotype-Dependant Growth Response 90

Plant Improvement 90
Source Material 90
Hybrid Testing and Pollinator (R-line) Development 91
Development and Improvement of Seed Parents 92
Variety Development 93
Synthetic Development 95
International Testing 96
Grain Quality 97
High Protein Lines 97
High Protein Hybrids 98

International Cooperation 99
ICRISAT Sahelian Center 99
Diseases 99
Striga 100
Insect Pests 100
Breeding 103
Cooperative Programs 105
Niger 105
Upper Volta 106
Senegal 110
Mali 112
Nigeria 113
Sudan 114

Workshops, Conferences, and Seminars 115

Looking Ahead 115

Publications 116

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66

PEARL MILLET

Physical Stresses

Cultivar Performance under Low Fertility

Nitrogen Uptake and Use

In a set of 20 diverse pearl millet genotypes tested in high fertility (HF = 100kg N/ha) and low fertility (LF = 20kg N/ha) environments over 2 years, we investigated variation in nitrogen uptake and use, and its relationship to crop growth and grain yield. The genotypes differed in biomass and grain yield but not in N uptake (Table 1). Despite taking up similar amounts of nitrogen, cultivars differed widely in use of nitrogen for biomass production (NEDM) and grain yield (NE$_G$). Genotype differences in growth, N uptake, and NEDM were similar at both fertility levels but there were significant cultivar × fertility interactions for grain yield and NE$_G$. These suggested that differential genotype response to fertility was primarily from NE$_G$ rather than N-uptake or NEDM.

Considerable genetic variability for NE$_G$ and a high correlation between NE$_G$ and grain yield

Table 1. Effects of N fertility levels on grain yield, N uptake, and N use for grain production (NE$_G$) in 20 pearl millet genotypes, ICRISAT Center, 1978 and 1980.

	Grain yield (kg/ha)		N uptake (kg/ha)		N use NE$_G$ g grain/g N	
Genotype	HF	LF	HF	LF	HF	LF
SC 2 (M)	3120	1670	112	45	28.7	36.7
BK 560	3090	1600	111	43	30.1	36.8
ICMS 7703	3060	1730	120	48	27.0	35.6
BJ 104	3030	1230	117	38	28.1	32.8
700112	2880	1470	95	45	32.3	33.3
SSC CI	2870	1360	104	39	30.0	34.8
SC 1 (M)	2840	1650	110	54	28.8	32.7
SER 17	2700	1380	105	48	27.5	28.6
700440	2540	1320	101	44	27.7	30.6
700471	2530	1120	96	35	28.9	31.8
700441	2490	1380	103	39	27.7	33.6
700651	2480	1330	105	48	25.8	29.0
3/4 HK	2400	1240	96	47	26.4	26.9
700772	2370	1230	109	44	23.7	28.3
ICI 266	2320	1390	94	43	26.2	33.7
Souna B	2310	1030	96	53	24.9	20.4
P3 Kolo	2170	1330	112	45	21.2	30.0
700331	2080	1190	108	50	21.9	24.1
IP 2757	2030	1220	107	41	20.0	29.8
700250	1980	1260	95	47	22.1	26.9
SE	±130	±124	±6.8	±5.1	±1.2	±1.9
CV %	10	18	13	23	9	12

(r = 0.75, P < 0.01) suggest that there is potential for genetic manipulation and agronomic gains, which is of interest because millet is generally grown in nutrient-poor soils where differences among millet cultivars in use of absorbed nitrogen could be of major importance.

Genotype × Fertility Interactions

We have also continued testing a set of 32 genotypes in HF and LF environments to evaluate genotype × fertility interactions (Table 2). After 3 years' testing we found highly significant (P < .001) effects of genotype, year, and fertility level on grain yield and yield components. Genotype × fertility interactions, however, where they occured, were smaller than the main effects or year × genotype and year × fertility interactions (all P < .001). Thus while genotypes differ in their response to fertility, this factor seems to be a smaller influence on grain yield than either primary effects of genotype, year, and fertility or genotype × year interaction.

Table 2. Pearl millet genotype means and variance ratio for genotype × fertility interaction over two fertility levels and three years for grain yield and yield components (n = 32).

Factor	Genotype mean		F ratio for genotype × fertility
	LF	HF	
Grain number (000)/m²	32.0	41.1	NS
Head number/m²	19.7	23.9	*
Grain number/head	1646.0	1784.0	*
1000 grain weight (g)	6.25	6.85	NS
Grain yield (g/m²)	205.0	278.0	*

Selection under Low Fertility

The relevance of breeding millet under high fertility (nitrogen) at experiment stations has been questioned because those conditions differ widely from conditions where the majority of pearl millet crops are grown. There is very little experimental evidence upon which to evaluate

Synthetics made from earlier generations selected for good yield under low fertility being tested for yield under two fertilizer regimes. Acceptable performance under low fertility is considered essential in breeding pearl millet lines for the SAT.

this objection; we have been working to resolve the question for the last 5 years. In 1983, we completed 2 years' testing of synthetic pearl millet varieties produced from early generation selections made under both HF and LF conditions.

We made crosses in 1978 between a common dwarf female parent and three lines selected on the basis of earlier performance under LF. Selection was initiated in the F_2 generation under both HF and LF environments in the same field, using 2000 F_2 plants in each environment. Selected plants were evaluated as F_3 progeny in 1980 in the same fertility environment in which they had been selected the year before, with dwarf and tall segregants handled separately. The fertility differential was large, as indicated by yields of the control hybrid ICH118 (4100 and 1950 kg/ha in HF and LF, respectively).

The 10 best F_3 progenies from each cross × selection environment × height class combination were recombined, producing 12 synthetic varieties. These were evaluated for 2 years in both HF and LF treatments in the same experiment, so selection environment × test environment interactions could be accurately measured. Year, test environment, and genotype (synthetic) were significant sources of variation in grain yield, as were year × test environment and year × genotype interactions. There was, however, no effect of selection environment or no interaction of selection and test environments. Average yields of synthetics from the LF selection environment were virtually identical to those from the HF selection environment in both the HF and LF comparisons (Table 3). It appears from these data that the probability of producing more widely adapted cultivars (especially for LF environments) will not be improved by initial selection under LF conditions.

While our results indicated no need to breed or to select under LF, the observed cultivar × fertility interactions (Tables 1 and 2) support testing advanced breeding products regularly under both HF and LF conditions. Acceptable performance under LF conditions should be an important criterion in advancing breeding products to final testing.

Table 3. Mean grain yield (kg/ha) of six tall and six dwarf pearl millet synthetics from low and high fertility selection environments as measured in both high and low fertility test environments.

Selection environment	Low fertility test		High fertility test	
	Tall	Dwarf	Tall	Dwarf
Low fertility	2240	1900	3460	2790
High fertility	2160	1890	3370	2790
SE	±87	±77	±87	±77

Crop Establishment

Seedling Emergence through Soil Crust

We developed a field technique to screen millet and sorghum for emergence through soil crust. Although the soil surface of our Alfisol fields rapidly forms a crust when rainfall is followed by sunshine, that sequence is unpredictable during the rainy season. We therefore simulated those conditions in the hot, dry season.

The soil was disced and rotary cultivated. Broadbeds were prepared and smoothed with a bed shaper. Plots 2 m long with a 0.5 m path between were laid out along each broadbed. Seeds were sown 30 mm deep for millet and 50 mm for sorghum with a John Deere 7100 planter with four planting units spaced 30 cm apart (Fig. 1a).

Figure 1a. Sowing with John Deere-7100 planter.

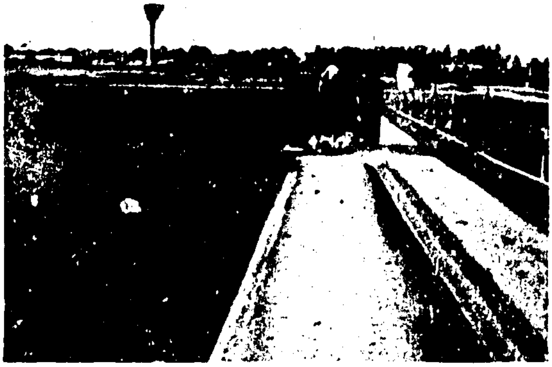
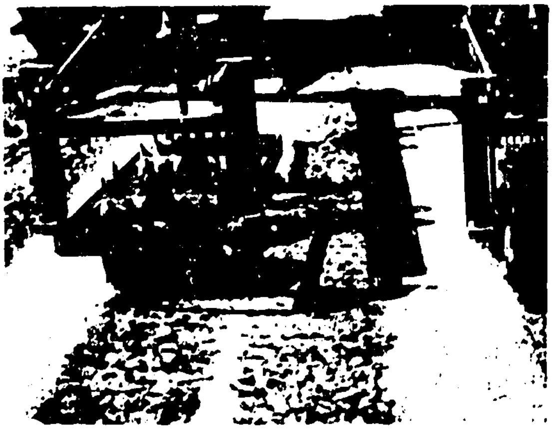


Figure 1b. Smoothing beds with bed shaper after sowing.

The beds were again smoothed with the bed shaper (Fig. 1b), and 35 mm of water was applied at 14 mm/hr when the wind was calm, with two parallel sprinkler lines 15 m apart. The plots were then left to dry for three days. The surface was then firm enough, so the crust in control plots could be broken with a crust breaker unit (Fig. 1c) without damaging plumules of germinating seeds—still 15 to 20 mm or more below the surface.

We measured crust strength, soil moisture, and soil temperature; Figure 2 shows strength of crusts in millet and sorghum trials. The relatively higher crust strength in the sorghum trial resulted from sorghum emerging later than millet. The seed zone (25 to 50 mm deep) contained only 8% moisture two days after sowing but moisture in soil layers below the seed zone was adequate for good emergence (wilting began only about 15 days after plants emerged). Soil temperature increased with drying, but only to 38 to 40°C, which did not inhibit germination or emergence of either crop.

Figure 1c. Breaking crust on control plots with a crust breaker unit.



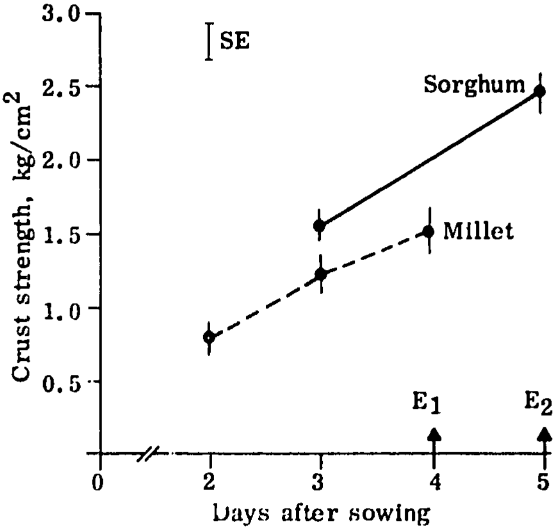


Figure 2. Crust strength measured from two 1983 trials. E_1 and E_2 indicate days millet and sorghum emerged.

Seedling emergence in control and crusted plots differed significantly ($P < 0.001$); genotypic differences also were highly significant ($P < 0.001$) in both millet and sorghum. Emergence where the crust was broken (control) was always higher than that through the crust (Fig. 3). The ratio of number of seedlings emerged through crust to the number emerged in the control (c/u ratio) was used to classify 285 germplasm lines of millet and 82 germplasm lines of sorghum for performance (Fig. 4). Among millet lines only three entries exceeded 80% emergence through the crust. One sorghum genotype (IS 2877) had a c/u ratio of 1.0.

The technique thus differentiated materials for ability to emerge through crusts. Using the technique, we will begin regular screening of germplasm and breeding materials.

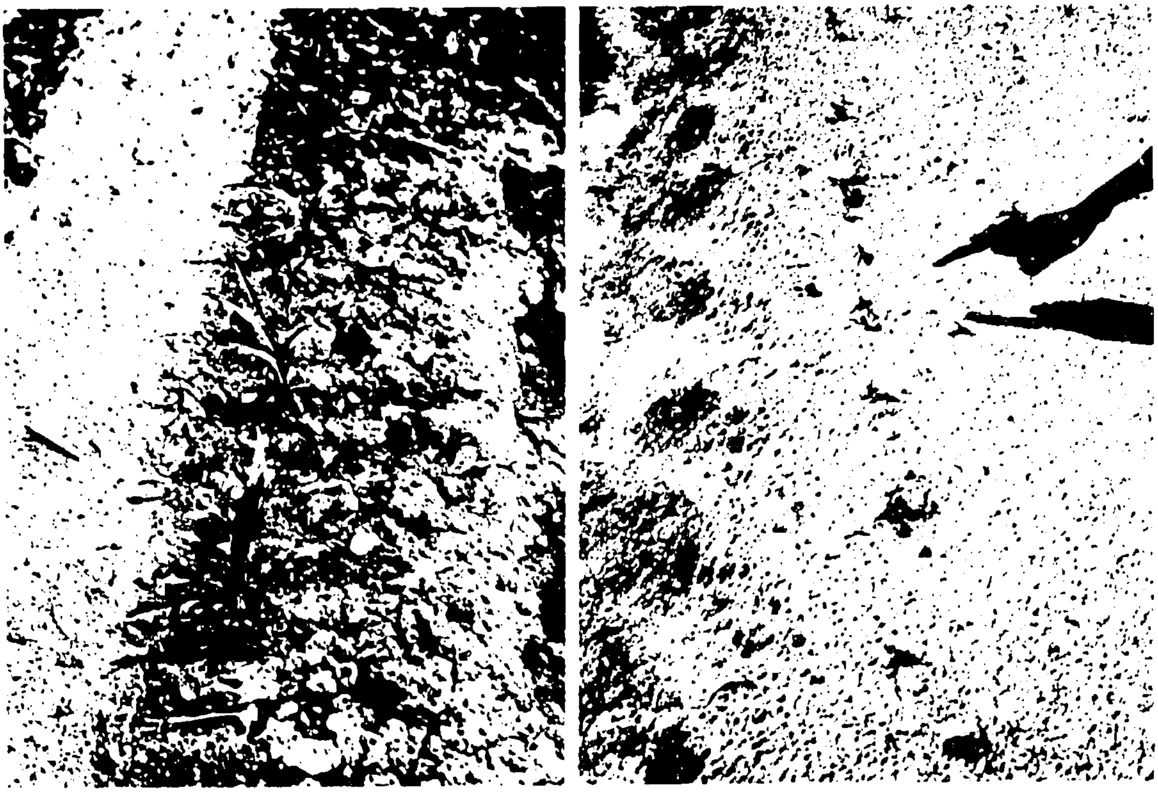


Figure 3. Emergence in control treatment where crust was broken (left) and through crust not mechanically broken (right).

Drought Screening

We previously reported (ICRISAT Annual Report 1976/77, 1978/79 and 1982) our drought screening work by withholding irrigation to impose drought stress in the hot, dry season (Jan to May). This approach is largely empirical with no quantification of the drought intensity or plant stress. We have been examining other techniques such as the line-source (LS) sprinkler irrigation method so we can quantify water applied to the crop. We have reported various conceptual analyses of data from the LS (ICRISAT Annual Report 1981 pp. 61-69), where the gradient was applied during grain filling to a crop that had been fully irrigated until flowering.

If the response of any variable to the moisture gradient created by LS is linear (as it was for 1981 grain yield data), then this technique may not provide any more information than that

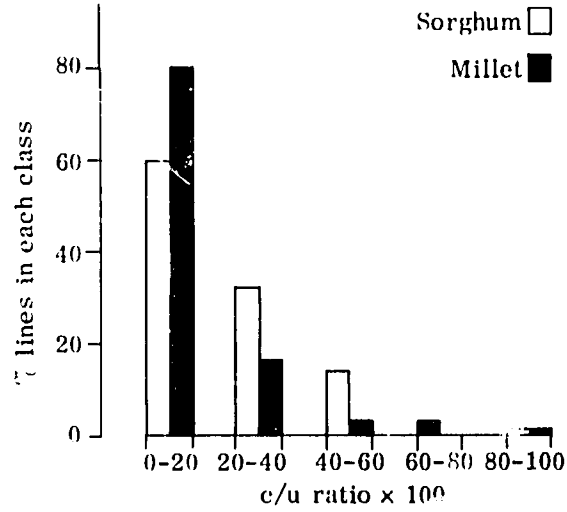


Figure 4. Classification of 285 lines of millet and 82 lines of sorghum by their c/u ratios.

$$c/u = \frac{\text{Emergence through crust}}{\text{Emergence through control}}$$

available from the simple stress/nonstress comparison (ES), provided that the moisture environments at the extremes of the LS gradient are similar to those in ES comparison. This concept was tested in 1982 with 32 genotypes grown in both the ES and LS systems. The comparisons were done in the same field under similar management, but as two separate experiments with replication within each experiment. Because there is no measure of water applied in the ES, we used the mean grain yield of the 32 genotypes in each moisture environment to quantify that environment for both the LS and ES. We then regressed individual genotype grain yields

Table 4. Comparison of the predicted pearl millet yields (YFI) under full irrigation (mean grain yield of 250 g/m²) and the regression slope (b) of yield vs drought stress intensity. Fit is the percentage of the varition explained by the regression ($r^2 \times 100$).

	Line source			Empirical screen		
Genotype	YFI	b	Fit	YFI	b	Fit
ICMS 7914	235	0.83	54	221	0.87	87
PSB 8	189	0.76	68	206	0.81	79
WC P3 80	230	0.99	79	223	0.87	88
ICH 435	261	1.27	83	272	0.90	61
BK 560	293	0.90	57	267	0.99	65
ICMS 7903	246	1.16	83	215	0.85	75
BJ 104	232	0.56	37	247	0.65	80
ICMS 8017	185	0.70	74	203	0.81	69
ICMS 7916	292	1.13	54	242	0.94	87
MC P1 80	250	0.77	47	240	0.86	86
ICH 433	309	1.39	76	295	1.43	83
SSC P 80	183	0.63	52	232	0.84	79
ICH 220	272	1.04	77	262	1.03	73
WC P4 80	258	1.06	76	245	0.94	70
ICH 118	230	1.14	79	240	1.13	77
ICH 426	276	1.28	61	267	1.37	84
IVS P2 80	204	0.96	76	237	1.01	95
MC A 80	308	1.25	82	249	1.02	88
ICMS 7806	268	1.34	69	249	1.11	82
MBH 110[1]	202	0.35	22	308	0.95	80
ICH 438	393	1.40	69	280	1.21	84
ICMS 8010[1]	223	0.96	73	298	1.39	96
ICMS 7703	243	0.93	81	295	1.19	85
ICH 226[1]	187	0.53	34	270	1.02	87
ICH 425	232	1.51	89	260	1.40	84
MBH 131	335	1.20	75	277	1.00	67
ICMS 7918[1]	235	0.81	74	265	1.20	96
ICMS 7844	239	0.98	69	214	0.86	77
ICMS 8025	210	1.07	86	212	0.83	80
ICMS 7909	267	1.22	78	265	1.31	81
MC P2 80	306	1.15	73	239	0.77	96
NEC P3 80	260	0.72	47	213	0.47	53

1. Slopes determined by the two techniques used differed significantly for these genotypes.

against mean grain yields and compared responses in the two techniques for differences in estimated yield potential without stress (mean yield of 250 g/m²) and slope (response to stress).

Because ES has only two clusters of points compared with a range of points in LS, the genotype regressions were expected to have higher regression coefficients in ES than in LS, which was true for 23 of 32 lines (Table 4). In general, regressions for the hybrids fit better than those for composites or synthetics, possibly because of more syncronous flowering in the hybrids. The exceptions to this were early hybrids (MBH 110, BJ 104, BK 560, and ICH 226), which had much lower values (slopes), because they escaped stress during the early grain-filling stage. We previously discussed this obivous association between early flowering and yield in end-of-season drought (ICRISAT Annual Report 1981 pp 62-63).

Only four genotypes differed in slopes between the two techniques (Table 4). In two of these fits were poor and the slopes low (MBH 110 and ICH 226), as they were early-flowering hybrids. There was no difference in the estimated values of nonstressed yields between the two techniques (t = 0.013).

There appears to be no obvious advantage in LS technique over ES, if the response in the LS is linear. LS technique, however, could be extremely useful when nonlinear responses are encountered. We will be comparing the two techniques under midseason stresses where we encounter a nonlinear response of grain yield to water applied.

Biotic Stresses

Diseases

Downy Mildew (*Sclerospora graminicola*)

Effect of temperature and relative humidity on asexual sporulation. Under field conditions, asexual sporulation of the downy mildew (DM) fungus occurs in pearl millet during the night, mostly after midnight. To determine the optimum temperature for asexual sporulation, we incubated 5 to 7 cm segments of systemically-infected pearl millet leaves (downy growth removed) in petri dish humidity chambers at each of seven temperatures: 5, 10, 15, 20, 25, 30, and 35°C. After 6.5 hr incubation, the downy growth that developed on the underside of the leaves was removed (with water) and the number of sporangia produced under each temperature regime determined. Data presented in Figure 5 show 20°C, as the optimum temperature for asexual sporulation, with some sporulation from 10 to 30°C, but none at 5 or 35°C.

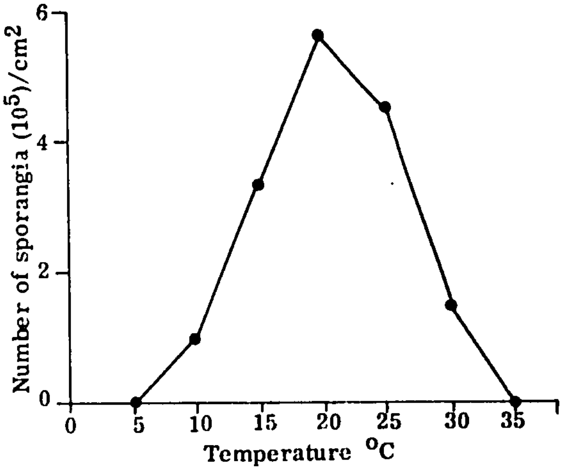


Figure 5. Effect of temperature on the production of sporangia.

To determine relative humidity requirements for sporulation, we treated systemically infected, uniformly-sporulating pearl millet leaves, cut into 5 to 7 cm segments, with old downy growth removed, as follows: (1) dry (growth removed with dry cotton)—segments kept in chambers (petri dish) lined with dry blotting paper (dry chambers); (2) wet (growth removed with wet cotton)—blotter dried, kept in dry chambers; (3) dry—sprayed with water, kept in dry chambers; (4) dry—kept in chambers lined with moist blotting paper (moist chambers); (5) wet—blotter dried, kept in moist chambers; and (6) dry—sprayed with water and kept in moist chambers.

The chambers were incubated at 20°C for 6 hrs. Humidity at the beginning and end of the incubation period was measured with a digital psychrometer. After incubation, sporangial growth was removed with water and sporangial concentration determined. Data represented in Figure 6 show clearly that sporulation was most on leaves incubated in moist chambers (RH >95%), and least on leaves kept in dry chambers (RH <82% at the beginning, and 90% at the end of the incubation period).

Appropriate temperature and relative humidity are clearly essential for asexual sporulation by *S. graminicola*. Although late night temperatures of 20 to 25°C may be common in the SAT, relative humidity of 95% could generally be limited to rainfall periods in millet-growing areas. Downy mildew incidence is often directly related to rainfall frequency.

Effect of light on sporangial infectivity. Seedling plants of susceptible cultivar 7042 were dipped in a sporangial suspension when they were 24 hr old, then incubated at 22°C in moist chambers under each of 4 light regimes: (1) 24 hr continuous light; (2) 24 hr continuous darkness; (3) 12 hr light then 12 hr darkness; and (4) 12 hr darkness then 12 hr light. Seedlings dipped into water and incubated 24 hr in continuous light or continuous darkness were maintained as controls. After incubation, the seedlings were transplanted into pots maintained in the greenhouse at 25 to 30°C. DM incidence records taken 15 days after planting showed high DM (86 to 92%) in all inoculation treatments, indicating that the light regime following sporangial inoculation does not affect DM infection in very young pearl millet seedlings.

Screening for resistance at ICRISAT Center. A 6-ha DM Nursery (DMN) was again operated during both the rainy and postrainy seasons,

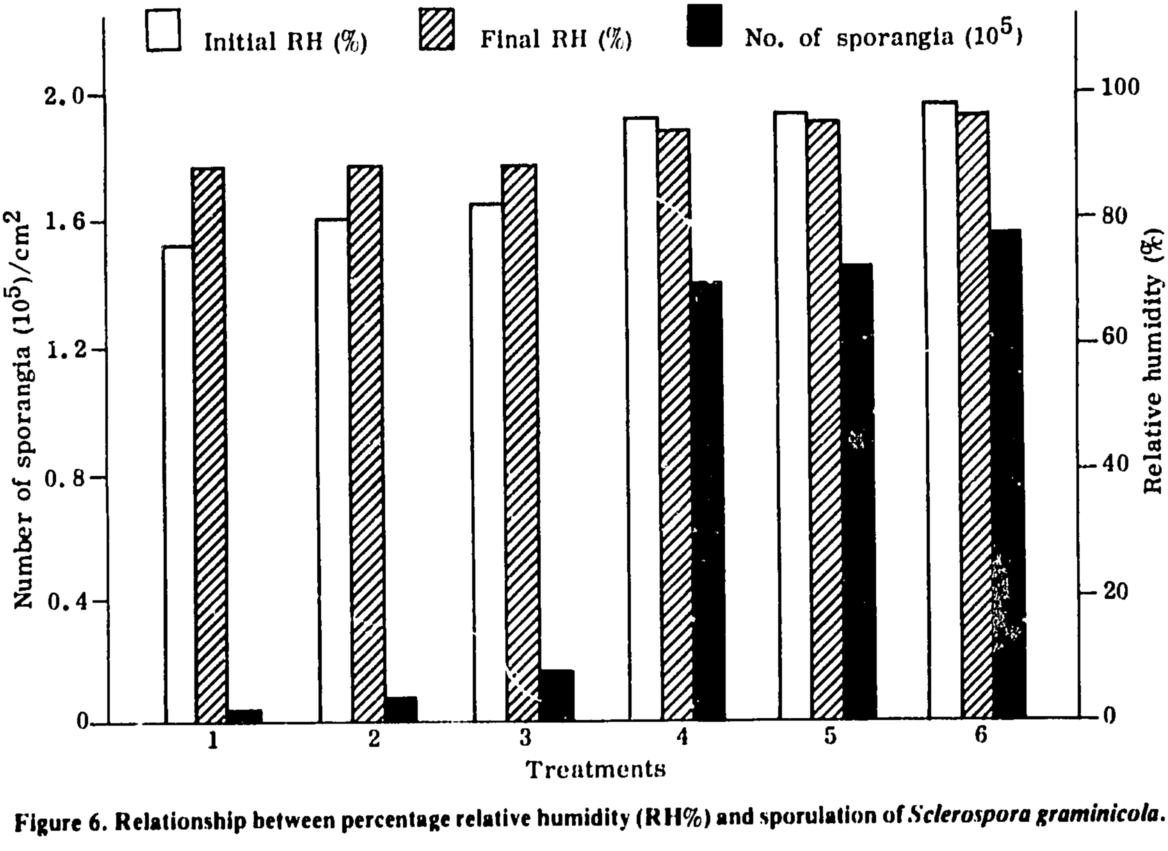


Figure 6. Relationship between percentage relative humidity (RH%) and sporulation of *Sclerospora graminicola*.

with approximately 7000 entries evaluated each season.

From among the 3163 germplasm accessions screened at ICRISAT Center for DM resistance, and the 2562 screened at Bhavanisagar for rust resistance during 1976 to 1982, we identified 428 accessions with high resistance to both diseases. We retested them for DM resistance at ICRISAT Center in 1983; 90 did not develop DM in either season and 75 others developed <5% mean DM. Their agronomic eliteness is being evaluated.

Of 92 entries (hybrids and populations) we screened from the All India Coordinated Millet Improvement Project (AICMIP) trials, 14 hybrids and 2 populations were DM free. Most of the others had <10% DM.

Multilocational testing. The multilocational disease-testing program continues to be invaluable in identifying stable resistance. The 45-entry International Pearl Millet Downy Mildew Nursery (IPMDMN), including 12 previously-tested entries, was sent to cooperators at 12 locations in India and West Africa. Data were received from all 12. No entry was free of DM at all locations, but 3 (SDN 503, IP 1930, EB 298-2-1-8) of the 12 previously tested had <10% DM incidence at all locations and others had >10% DM only at Samaru and Kano, Nigeria. Among new entries, P 472 and P 310 were either free or had <5% DM at all locations, and P 1610, P 1607, and P 105 developed no more than 10% DM at any location. Each test entry, except BJ 104, averaged <10% DM incidence across locations.

Development of resistance in susceptible genotypes. BJ 104, the most popular pearl millet hybrid in India, has become increasingly susceptible to DM in recent years (AICMIP Annual Reports 1979-83). Drawing on earlier experience in developing a DM-resistant version of the susceptible cultivar, 7042, through a few generations of selection in the DM nursery at ICRISAT Center, we launched a program to improve the parents of BJ 104, 5141A and J 104. The success of such an exercise depends on both residual variability for DM in the susceptible cultivar and availability of high DM pressure during selection. Although the original lines showed 70 to 97% DM during the 1982 rainy season (July to September), DM-free plants with correct parental phenotypes were detected in both lines. DM-free plants of J 104 and 5141B were selfed and DM-free 5141B plants were crossed to DM-free 5141A plants. Ear-to-row progenies were grown in the DMN November 1982 to January 1983 when selections again were made for DM-free plants. During the 1983 summer season (February to May), we raised 214, 337, and 31 progenies, respectively, of 5141B, 5141A, and J 104. Many 5141A and 5141B progenies remained DM-free but only 5 from J 104 did (Table 5). The Indian Agricultural Research Institute (IARI) millet breeder from New Delhi, who developed the A and B lines, visited ICRISAT in May 1983 to verify the resistant selections' identities. Many progenies were similar to the original lines, but only four 5141A and B pairs and one J 104 progeny were selected as completely true to type.

Bulk seed of four A line selections was sent to several DM hot-spot locations in India to evaluate DM resistance during the 1983 rainy season. The bulks remained DM-free at Aurangabad, Coimbatore, Durgapura, ICRISAT Center, and Jamnagar, and developed less than 1% DM at Hissar and Ludhiana and 9% at Mysore. One pair of A and B lines and two J 104 selections were also tested at Cuddalore (Tamil Nadu), a known hot-spot for DM, where the A and B pair and one J 104 selection did not develop DM. Seed of the A and B pair was immediately increased in a greenhouse (Fig. 7) at ICRISAT Center (October 1983 to January 1984) so seed could be supplied to the Indian national program for further increase during the 1984 summer season, and for eventual commercial production of BJ 104.

The same approach is being used to remove DM susceptibility from several other breeding products, including ICP 220, ICP 241 and ICMPE 3. All three have passed through one cycle of selection.

We have demonstrated this method of

Figure 7. Postrainy-season use of greenhouse space to increase seed of DM-resistant versions of 5141A and B in time for summer season (1984) multiplication by the national program to enable continued use of the popular Indian hybrid, BJ 104.

Table 5. Improvement of parent lines of pearl millet BJ 104 (5141A × J 104) for resistance to downy mildew (DM).

Entry	Generation	No. plants or progenies	DM incidence (%)			
			Test material		Controls	
			Mean	Range	Original line	Susceptible hybrid NHB 3
5141A	S_0	1064[1]	70			80
	S_1	80[2]	11	0 42		92
	S_2	337[2]	10	0 69	71	96
5141B	S_0	762[1]	80			80
	S_1	228[2]	17	0 55		92
	S_2	214[2]	8	0 100	90	96
J 104	S_0	333[1]	97			80
	S_1	19[2]	44	0 88		92
	S_2	31[2]	25	0 100	81	95

1. Number of plants.
2. Number of progenies.

improving DM resistance in a landrace cultivar and in highly-specialized lines like 5141A and B. We plan to continue to exploit the technique to improve DM resistance, thereby possibly extending the useful life of otherwise valuable cultivars.

Ergot (*Claviceps fusiformis*)

Variations among isolates. Isolates of pearl millet ergot pathogen *Claviceps fusiformis* were collected from 8 locations in India: Aurangabad (ABD), ICRISAT Center (ICR), Ludhiana (LDH), Coimbatore (CBR), Jobner (JBN), Pune (PUN), Kovilpatti (KPT), and Mysore (MYS), and studied for morphologic and pathogenic variations. Sclerotia were examined for shape, size, cavities, and content and viability of macro- and microconidia. Sclerotia from ABD and ICR were both largest (5 × 2.5 mm) and heaviest (1.4 g/100); those from MYS, smallest (3 × 2 mm) and lightest (0.4g/100) (Fig. 8).

There were fewest cavities in MYS sclerotia (4/sclerotium, average) and most in KPT sclerotia (15/sclerotium). Size and ratios between the number of macro- and microconidia of sclerotia varied widely from different locations. Time to germination of macroconidia from sclerotia (in sterile distilled water at 25°C) varied from 24 hr in ABD and JBN isolates to 50 hr in the KPT isolate. The PUN isolate did not germinate (probably died). Host and environmental differences may play significant roles in the variability among ergot samples.

The isolates' growth characteristics differed on Kirchoff's agar at 25°C. In a pathogenicity test using 10-day-old culture inoculum and 6 pearl millet genotypes (3 resistant and 3 susceptible), the KPT isolate showed maximum virulence (42% mean severity) followed in decreasing order by JBN, LDH, ABD, CBR, ICR, and MYS. But those rankings need to be confirmed. The studies were conducted in collaboration with a millet pathologist from Punjab Agricultural University, Ludhiana, India, during his two months as a visiting scientist at ICRISAT Center.

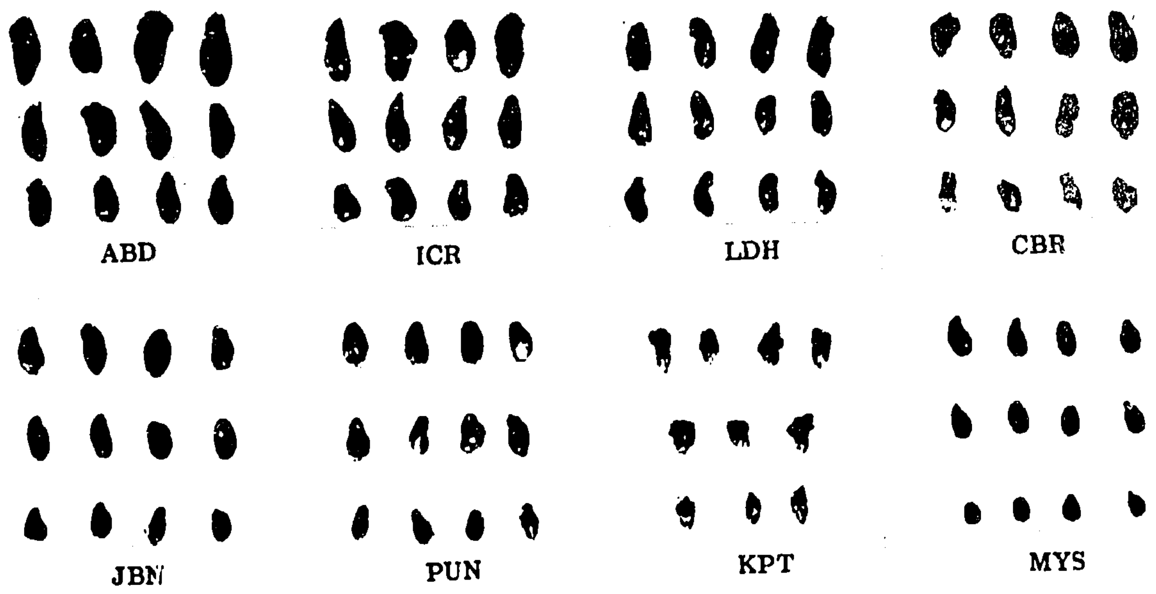


Figure 8. Variations in morphology of ergot sclerotia among isolates from eight locations in India.

Table 6. Performance of 14 IPMEN entries at Samaru, Nigeria, and six Indian locations in 1981, 1982, and 1983.

	Ergot severity (%)[2] at																	
	Samaru		Aurangabad		ICRISAT Center			Jamnagar			Ludhiana			New Delhi			Mysore	
Entry	1982	1983	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983	1982	1983
ICMPE[1] 134-6-9	<1	<1	1	<1	<1	<1	<1	<1	0	<1	5	<1	1	1	2	0	<1	<1
ICMPE 134-6-11	<1	1	5	<1	<1	1	<1	<1	<1	<1	2	<1	2	1	2	0	<1	0
ICMPE 134-6-41	<1	1	5	<1	<1	1	<1	<1	<1	<1	1	<1	1	1	2	<1	<1	0
ICMPE 134-6-34	<1	1	2	1	<1	1	<1	1	<1	<1	1	<1	5	1	2	<1	<1	0
ICMPE 134-6-25	1	<1	1	1	<1	<1	<1	<1	0	<1	3	<1	3	1	1	<1	2	0
ICMPE 13-6-27	6	<1	1	2	5	1	1	7	1	1	5	2	3	5	<1	1	3	0
ICMPE 13-6-30	1	1	1	1	3	2	2	4	1	<1	7	<1	8	4	4	2	1	1
ICMPES 1	1	0	1	1	-[3]	2	1	-	1	2	-	1	3	-	1	1	1	-
ICMPES 2	<1	1	2	1	-	<1	<1	0	0	<1	-	<1	2	-	3	0	<1	<1
ICMPES 23	0	1	2	1	0	3	2	-	0	1	-	5	2	-	2	<1	1	0
ICMPES 27	0	<1	1	1	-	1	<1	-	0	<1	-	<1	2	-	1	<1	3	0
ICMPES 28	<1	<1	3	2	-	7	1	-	<1	1	-	<1	2	-	3	2	1	0
ICMPES 32	1	1	4	16	-	2	1	-	<1	2	-	1	2	-	<1	1	1	1
Susceptible control	83	89	97	91	99	98	90	41	58	44	67	65	66	63	23	52	33	62

1. ICMPE (S) = ICRISAT millet pathology ergot-resistant lines (sib-bulk).
2. Based on 20-40 inoculated inflorescenes/entry in two replications.
3. - = Entry not included.

Screening for resistance. During the summer and rainy seasons we screened more than 2600 entries for ergot resistance under different screening phases at ICRISAT Center (Fig. 9).

Identifying resistance To identify new sources of resistance, we screened 102 selections (S_2 and S_3) from the 1982 screen of germplasm lines from Ghana, Nigeria, Tanzania, and Togo. Most lines developed high ergot (>30% severity); the few with less ergot had poor seed set, so no selection was made.

Multilocational testing. The 29-entry, 1983 International Pearl Millet Ergot Nursery (IPMEN) was tested at 10 locations in India, 1 in Nigeria, and 1 in Niger. Although no entry remained ergot-free at all locations, 18 showed across-location mean severity of not more than 1%, and 10 between 2 and 8% compared with 65% on the susceptible control, BJ 104. All resistant lines developed at ICRISAT Center have shown high ergot resistance across locations for 2 or 3 consecutive years (Table 6). At Samaru, Nigeria, where most previously-tested lines have shown susceptibility, ICRISAT millet pathology ergot sib-bulk (ICMPES) lines have shown high resistance in 2 years of testing. They have shown resistance stability in both India and Nigeria. But wider testing is needed in Africa, to confirm their stability.

Figure 9. Field screening for ergot resistance involves spraying an aqueous suspension of *Claviceps fusiformis* conidia on heads at protogyny. Over 2600 entries were screened at ICRISAT Center during 1983.

Developing resistance. Developing ergot-resistant lines continued with major emphasis on concentrating resistance genes from diverse sources and selecting resistant progenies with desirable agronomic traits. During the 1982 summer and rainy seasons, we screened 2044 lines in F_1 to F_7 generations of crosses among ergot-resistant F_5 to F_8 lines, ergot-low susceptible (ELS) lines, and between ergot-resistant × DM-resistant lines. We selected about 2700 single plants with high ergot resistance (<5% severity) for further evaluation. During the rainy season we evaluated 14 of the ergot-resistant sib-bulks (ICMPES lines) for ergot reaction and agronomic traits under high ergot pressure. Several showed high ergot resistance and were superior to controls in head length, 1000-grain weight, and grain yield (Table 7). They must be tested more widely in India.

Utilizing resistance. We continued efforts to transfer ergot resistance into established B and R lines by backcrossing. Third backcross progenies were screened and ergot-resistant segregants were selected. Ergot-resistant (ER) progenies from crosses of ICP220 × ER, 5054B × ER, 5141B × ELS, at F_3 to F_6 generations were selected. Ergot-resistant lines that are maintainers on 5054A, 5141A, and ms 81A are being converted to A lines by backcrossing. Seed of ergot-resistant lines were supplied to several

Table 7. Evaluation of ergot-resistant pearl millet sib-bulks for ergot reaction, grain yield, and and other agronomic characters, ICRISAT Center rainy season, 1983.

Entry	Ergot infection severity (%)[2]	Tillers/ plant[1]	Plant height[1] (cms)	Head length[1] (cms)	1000-grain weight[1] (g)	100-plant yield[1] (kg)
ICMPES 28	0	2.1	158	31	7.5	2.4
ICMPES 29	0	1.9	155	30	7.1	1.8
ICMPES 6	1	2.1	148	20	8.4	1.8
ICMPES 33	<1	1.6	190	24	6.4	1.6
ICMPES 9	<1	2.0	165	22	8.3	1.6
ICMPES 16	0	2.2	149	24	7.5	1.6
ICMPES 31	<1	2.1	168	25	7.8	1.5
ICMPES 15	<1	2.3	173	25	9.3	1.5
ICMPES 27	0	1.7	148	29	8.8	1.5
ICMPES 10	<1	2.4	140	22	7.1	1.3
ICMPES 2	0	2.4	137	21	5.6	1.2
ICMPES 11	<1	1.7	149	22	7.6	1.2
ICMPES 1	<1	2.9	197	22	6.0	0.9
ICMPES 17	<1	2.0	150	22	8.0	0.8
Controls						
ICMS 7703	9	1.9	160	23	8.3	1.7
BJ 104	23	3.6	113	14	6.0	1.1
SE		±0.3	±6	±1	±0.7	±0.3

1. Mean of two replications.
2. Based on 59-103 open inoculated heads/replicate.

breeders in India for their resistance breeding programs.

Inheritance of resistance. We carried out genetic analyses on ergot reactions of parents, and F_1, F_2, BC_1, and BC_2 progenies of two crosses involving two susceptible (ICP 220 and J 104) and two resistant (ICMPE 13-6-9 and ICMPE 134-6-9) genotypes. Inheritance of ergot resistance was quantitative and controlled by 5 to 10 factors. Heritability estimates in a narrow sense were 0.55 and 0.31 and genetic advances 40 and 20% respectively, for ICMPE 134-6-9 × J 104 and ICP 220 × ICMPE 13-6-9.

Although inheritance of resistance is relatively complex, the genetic advances obtained in the two crosses suggest that resistance may be effectively transfered.

Smut (*Tolyposporium penicillariae*)

Primary source of inoculum. Using a Metronics roto-rod sampler, we monitored *T. penicillariae* airborne sporidia in smut nurseries during the 1980 crop season at Hissar and the 1982 and 1983 seasons at ICRISAT Center. The plots were either artificially infested by adding smut sporeballs to the soil or naturally infested with the previous season's field inoculum. Increased sporidia were trapped after rain showers or irrigation. A similar result was obtained from a pot experiment in a screenhouse. The results indicate that teliospores left in the soil by infected plants the previous season are the main source of primary inoculum.

Screening for resistance. About 2800 lines were screened for smut during the 1982-83 postrainy season and the 1983 rainy season at ICRISAT Center (Fig. 10).

Identifying resistance. Of 48 promising selections from 1982, artificially inoculated and evaluated in a replicated trial in the pearl millet smut nursery during the 1983 rainy season, 40 remained smut free. The remaining 8 had 1 to 10% smut infection compared with 76% infection on the susceptible control, BJ 104. We selected 136 single plants with smut resistance and superior agronomic traits for further evaluation.

Multilocational testing. The 30-entry, 1983 International Pearl Millet Smut Nursery (IPMSN) was tested at five Indian and four West African locations. Mean smut severities across locations varied from 1 to 11% infection compared with 44% for the susceptible control. Five entries, SSC FS-252-S-4, ICI 7517-S-1, EBS 46-1-2-S-2, EB 112-1-S-1-1, and EB 132-2-S-5-2-DM-1, exhibited stable resistance for 2 to 6 years of testing at different locations. Another 4 ICRISAT Center-developed lines, ICMPS 101-1, 904-3, 1600-4 and 2001-2 were highly resistant across locations for 1 to 2 years of testing (Table 8). Two of the smut-resistant lines, P 489-S-3 and ICMPS 101-1, also resisted DM in both India and West Africa.

Developing resistance. During the postrainy and rainy seasons, we screened 2181 lines at F_3 to F_6/S_6 stages; 94% were smut free; the remaining 6% had smut severities of 1 to 20% compared with 76% on the susceptible control, BJ 104. Among dwarf, medium-tall, and tall groups many lines now have both high smut resistance and desirable agronomic traits. Prolonged rains during the 1983 rainy season prevented full expression of agronomic traits and reduced the number of plants selected. Several advanced generation lines from 1982 were sib-mated to produce sib-bulks designated by ICMPS numbers and evaluated multilocationally through the 1983 IPMSN.

Utilizing resistance. We evaluated 14 F_1 test hybrids, ms lines × smut resistant (SR) lines, 198 S_1 progenies of a smut-resistant composite (SRC) C2 cycle, 2 synthetics, 62 F_6 lines (23 D_2B × SR lines), 55 diallel F_1s (SR × SR) and 105 A and B pairs.

Figure 10. Field screening for smut resistance involves inoculating heads at the boot-leaf stage with an aqueous suspension of *Tolyposporium penicillariae* sporidia. We screened 2800 lines during 1983.

All 14 test hybrids were highly susceptible (20% smut severity), but 41 SRC S_1 lines, 31 F_6 (23 D_2B × SR), 33 SR diallel F_1s and 37 A and B pairs were smut free, and a large proportion of the remaining lines showed smut severities of only 1 to 10%.

One synthetic, ICMS 8282, and 2 experimental varieties, ICMV 82131 and ICMV 82132, showed high smut resistance, good yield potential, and resistance to DM.

Table 8. Smut severity (%) of the best smut-resistant pearl millet lines evaluated for several years at locations in India and four West African countries.[1]

	Indian locations															
	Hissar						Jamnagar						ICRISAT Center			
	Year						Year						Year			
Entry[2]	78	79	80	81	82	83	78	79	80	81	82	83	80	81	82	83
SSC FS 252-2-4	0	0	0	–[3]	0	0	1	1	0	0	0	0	0	0	0	0
ICI 7517-S-1	0	0	0	<1	<1	0	<1	<1	0	<1	0	0	0	0	<1	0
EB 132-2-S-5-2-DM-1	6	2	<1	1	<1	0	2	1	<1	1	0	0	<1	1	<1	0
EBS 46-1-2-S-2	–	–	<1	<1	0	0	–	–	<1	2	<1	0	4	<1	<1	0
EBS 112-1-S-1-1	–	–	<1	0	<1	0	–	–	0	0	0	0	0	0	0	0
P 489-S-3	–	–	–	<1	0	<1	–	–	–	0	<1	0	–	0	0	0
ICMPS 101-1	–	–	–	–	0	0	–	–	–	–	<1	0	–	–	0	0
ICMPS 904-3	–	–	–	–	0	0	–	–	–	–	<1	0	–	–	0	0
ICMPS 1600-4	–	–	–	–	<1	<1	<1	–	–	–	0	0	–	–	0	0
ICMPS 2001-2	–	–	–	–	<1	<1	–	–	–	–	<1	0	–	–	<1	0
Susceptible control	15	25	30	11	36	78	4	11	31	18	58	44	61	91	72	82

	West African locations														
	Bambey (Senegal)						Samaru (Nigeria)				Kamboinsé (Upper Volta)			Sadoré (Niger)	
	Year						Year				Year			Year	
Entry	78	79	80	81	82	83	78	80	81	83	78	79	82	81	83
SSC FS 252-2-4	<1	1	0	–	1	2	12	4	4	19	0	0	0	0	<1
ICI 7517-S-1	1	0	1	0	<1	1	13	10	3	2	0	0	<1	4	<1
EB 132-2-S-5-2-DM-1	24	7	1	2	1	1	32	15	6	12	1	1	1	1	<1
EBS 46-1-2-S-2	–	–	1	1	–	1	–	21	4	6	–	–	1	1	0
EBS 112-1-S-1-1	–	–	<1	<1	3	1	–	14	1	–	–	<1	1	<1	<1
P 489--S-3	–	–	–	9	2	2	–	–	1	1	–	–	<1	<1	<1
ICMPS 101-1	–	–	–	–	<1	1	–	–	–	3	–	–	–	–	<1
ICMPS 904-3	–	–	–	–	<1	1	–	–	–	5	–	–	–	–	0
ICMPS 1600-4	–	–	–	–	2	1	–	–	–	8	–	–	–	–	<1
ICMPS 2001-2	–	–	–	–	<1	1	–	–	–	7	–	–	–	–	6
Susceptible control	17	11	31	84	24	54	65	68	51	32	–	67	43	28	47

1. Mean severity of infection based on 20-40 inoculated/bagged heads in two replications.
2. SSC = Super Serere Composite from Uganda;
   ICI = ICRISAT Inbred;
   EB = Ex-Bornu (Nigeria);
   EBS = Ex-Bornu sibbed,
   P = Senegal;
   ICMPS = ICRISAT Millet Pathology Smut lines.
3. – = Entries not included, data not received or nursery not conducted.

Rust (*Puccinia penniseti*)

Screening for resistance. We planted 428 germplasm accessions with combined resistance to DM and rust for retesting against rust at Bhavanisagar during the 1983 rainy season. Of 231 entries with enough plants for evaluation, 3 entries, IP 537-B, 700481-35-5, and IP 6093 (P 209) remained completely rust free. Based on the absence of rust on the top four leaves, 27 entries were rust free and 71 others developed <10% rust, but had light-to-severe rust on lower leaves.

In addition, 163 single plant selections of 5141 A and B, with high DM resistance, were evaluated for resistance. Their rust reactions varied but none had acceptable resistance.

Several DM-resistant selections of cultivar 7042 (with high rust resistance in earlier tests at ICRISAT Center) were evaluated at Bhavanisagar, Kovilpatti, and ICRISAT Center. Two selections remained rust free.

Multilocational testing. A 45-entry International Pearl Millet Rust Nursery (IPMRN) was evaluated at several locations in India under natural rust pressure, which was low at Ludhiana, Hissar, and Durgapura, moderate at Aurangabad and Pune, and severe at Coimbatore and Bhavanisagar. No entry was rust free at all the locations but seven, P 2890, P 1577, P 1591, P 1564, P 1581, P 2880, and IP 2084-1 had <10% rust at all locations. Three others, P 1592, 45-329, and P 15, had <10% except at Durgapura. Many lines have previously shown high rust resistance over several years in multilocational testing in India (Table 9).

Table 9. Mean rust incidence (%)[1] of 18 pearl millet entries evaluated in the IPMRN from 1977-1982 at seven locations[2] in India.

Entry	Origin	Year of test					
		1977	1978	1979	1980	1981	1982
700481-21-8	Nigeria	7	11	4	4	4	2
700481-22-8	Nigeria	8	6	2	13	5	4
700481-23-2	Nigeria	7	5	6	12	6	5
700481-33-1	Nigeria	6	5	4	14	5	8
700481-35-5	Nigeria	7	9	4	12	6	13
700481-7-5	Nigeria	1	7	3	11	6	11
Souna Mali	Mali	-[3]	-	4	10	6	8
IP 537-B	USA	-	7	3	9	6	11
IP 2084-1	India	-	-	-	7	6	6
P 15	Cameroon	-	-	-	7	7	8
P 24	Cameroon	-	-	-	16	6	10
D 212-P1	Niger	-	-	-	10	6	11
P 29	Cameroon	-	-	-	15	6	12
P 1564	Senegal	-	-	-	-	4	7
P 1581	Senegal	-	-	-	-	2	3
P 542	Mali	-	-	-	-	7	10
IP 3104	India	-	-	-	-	5	13
P 543	Mali	-	-	-	-	6	12
Susceptible control NHB 3		51	42	34	31	26	34

1. Rust % estimated using modified Cobb's scale on the top four leaves only.
2. Locations = Coimbatore, Durgapura, Hissar, Kovilpatti, Kudumiamalai, Ludhiana, and Pune.
3. - = Not tested.

Multiple Disease Resistance

Of 231 accessions retested for DM at ICRISAT Center and for rust at Bhavanisagar in 1983, one entry, IP 537-B, developed neither DM nor rust; 95 entries showed high DM and rust resistance (<3% DM and <10% rust on top four leaves). We have made many single plant selections and are evaluating their progenies for agronomic traits.

Screening pearl millet lines simultaneously for resistance to DM, ergot, smut, and rust was continued. During the 1983 rainy season, we screened 198 entries consisting of AICMIP hybrids, populations, and ms lines, and entries from IPMDMN, IPMEN, and IPMSN.

Among the AICMIP entries, 83% showed <10% DM incidence, only 4% had <10% smut severity, and none was resistant to ergot. Among the three international disease nurseries 97 to 98% of entries were found resistant to DM, whereas the frequency of smut resistant entries ranged from 45 to 100%, and the frequency of rust resistant entries, from 13 to 72% (rust scores taken under natural disease pressure). Although many entries in the disease nurseries resisted DM, smut, and rust, none except IPMEN entries resisted ergot. Many IPMEN entries had resistance to all four diseases (Table 10).

Insect Pests

We have studied the insect pest complex associated with pearl millet on four cultivars over 8

Table 10. Sources of pearl millet multiple disease resistance identified at ICRISAT Center during the rainy (R) 1981, summer (S) and rainy 1982, and rainy seasons 1983.

	Ergot (%)[2]				Smut (%)[2]			DM (%)				Rust (%)[3]	
	1981	1982[4]		1983[4]	1981	1982[4]	1983[4]	1981[5]	1982[4]		1983[4]	1982[4]	1983[4]
Entry[1]	R	S	R	R	R	R	R	R	S	R	R	S	R
ICMPE 134-6-25	<1	0	<1	<1	0	0	0	0	0	0	0	0	10
ICMPE 134-6-41	<1	<1	<1	<1	0	0	<1	0	1	0	0	0	25
ICMPE 134-6-9	<1	1	0	<1	0	-[6]	0	0	1	0	0	0	0
ICMPE 134-6-11	<1	0	<1	<1	0	0	0	0	0	5	9	0	25
ICMPE 140-3	1	<1	3	-	0	0	-	0	0	0	-	0	-
ICMPE 13-6-27	5	0	0	1	0	0	0	0	0	0	0	0	10
ICMPE 13-6-30	<1	-	2	2	-	0	0	0	-	0	0	-	10
ICMPE 134-6-34	3	0	1	<1	0	0	0	4	1	0	3	0	10
ICMPES 1	-	-	2	1	-	0	0	-	-	2	4	-	10
ICMPES 2	-	-	<1	<1	-	0	0	-	-	3	2	-	25
ICMPES 23	-	-	3	2	-	0	0	-	-	0	1	-	0
ICMPES 27	-	-	1	<1	-	0	0	-	-	6	-	-	5
ICMPES 28	-	-	7	1	-	0	0	-	-	0	1	-	5
ICMPES 32	-	-	2	1	-	0	0	-	-	0	4	-	5
Controls													
BJ 104	83	67	94	91	54	48	82	32	5	41	34	40	100
WC-C75	74	-	66	76	3	2	30	2	-	5	1	-	

1. ICMPE (S) = ICRISAT millet pathology ergot-resistant lines (sib-bulk).
2. Based on 20-40 inoculated heads from two replications, both ergot and smut inoculations made on the same DM-free plant.
3. Based on modified Cobb's scale.
4. Screened in multiple disease nursery.
5. Based on DM reactions during the 1980-81 postrainy season in ICRISAT Center DM nursery.
6. - = Data not recorded or entry not included.

crop seasons. At ICRISAT Center we found 85 insect and mite species associated with millet, 23 of which are new records. Among the more important ones were shoot fly (*Atherigona approximata*), aphid (*Rhopalosiphum maidis*), earhead caterpillars (*Heliothis armigera* and *Eublema silicula*), head bugs (various species), blister beetle (*Cylindrothorax tenuicollis*), and thrips (*Thrips* spp). A survey in south India showed that shoot fly, head bugs, leaf folder (*Marasmia suspicalis*), gray weevil (*Myllocerus undecimpustulatus*), and midge (*Geromyia penniseti*) were serious pests on pearl millet grown by local farmers.

Pearl millet lines differ in susceptibility to important insect pests. We have identified those less damaged by shoot fly, spider mites (*Oligomychus indicus*), gray weevil, leaf folder, armyworm (*Mythimna separata*) aphids, shoot bugs (*Peregrinus maidis*), *Heliothis*, and thrips under natural free-choice conditions.

Armyworm (*Mythimna separata*)

Using a technique we developed to screen for resistance to armyworm, we identified six cultivars less susceptible to this pest. Our studies on the combining ability of cultivars and genetic interactions using 4 ms lines have given us combinations with good combining ability for resistance to armyworm.

Heliothis armigera

Damage was recorded on 219 cultivars at ICRISAT Center during the 1983 rainy season. Dwarf cultivars with dense anther covering suffered more damage than those with clean heads.

Microbial Associations

Biological Nitrogen Fixation

Relationship between Assay Methods of Measuring Nitrogenase Activity

Higher nitrogenase (C_2H_2 reduction) activity has been reported with the improved soil-core assay (planted-core assay) technique than with regular soil-core assays (ICRISAT Annual Report 1982, pp. 83-84). We estimated nitrogenase activities of 7 lines of field-grown pearl millet by both regular soil-core assay and planted soil-core assay techniques. The two methods gave a positive relationship ($r = 0.70$, $P < 0.05$) for C_2H_2 reduction activity associated with field-grown plants.

We also studied the relationship between the tube-culture assay technique (ICRISAT Annual Report 1982, pp. 86-88) and field-assay methods of measuring nitrogenase activity associated with millet lines. Seven lines of pearl millet field grown during the rainy season were assayed at the early-flowering, grain-filling stage for nitrogenase activity by the planted soil-core assay technique. Nitrogenase activities associated with 20-day-old seedlings of the seven lines grown in tubes filled with unsterilized Alfisol were also estimated. The correlation between nitrogenase activity estimated by tube-culture assay and by planted soil-core assay was positive ($r = 0.86$, $P < 0.01$).

Likewise maximum field activity of nine millet lines recorded with regular soil-core assays over 3-6 seasons and the activity recorded with seedlings grown in tubes filled with sand : farmyard manure (97:3 w/w) and vermiculite were positively related ($r = 0.65$, $r = 0.67$, $P < 0.05$).

Nitrogen Balance Studies

A pot trial was conducted with BJ 104 grown in an unsterilized Alfisol with nitrogen equivalent to 0, 20, and 40 kg/ha and inoculated with one of three cultures of nitrogen-fixing bacteria. Inoculating potted plants with nitrogen-fixing bacteria produced significantly higher net nitrogen balances than those in the noninoculated (control) plants. A maximum positive nitrogen balance of 322 mg/pot over an unplanted control pot came from a treatment (across nitrogen levels) inoculated with *Azospirillum lipoferum* (ICM 1001). Across inoculation treatments the highest nitrogen balance of 240 mg/pot was with the equivalent addition of 20 kg N/ha.

During the 4th year (1983 rainy season) of a long-term field trial initiated in 1980, total dry-matter production across cultivars did not differ between treatments (with 20 kg N/ha, and without nitrogen). Mean total dry-matter yield of cultivars across nitrogen levels varied significantly; the highest, 4390 kg/ha, was from line 700256. Nitrogen uptake by grains during the 1983 rainy season by millet cultivars across nitrogen treatments also did not vary significantly. The maximum total nitrogen uptake of 44 kg/ha was by line 700256 grown with no nitrogen added.

In our irrigated, long-term, nitrogen-balance trial, several tropical grasses have been grown for 5.5 years without nitrogen fertilizer added. The crop receives 40 kg P_2O_5/ha every year and is irrigated during the dry season. Maximum dry-matter production (329 t/ha including 2322 kg N) was by hybrid *Pennisetum americanum* × *P. purpureum* (NB 21) over the whole term. Several other grasses, including millet × napier grass hybrids, also produced large dry-matter yields. But *Panicum antidotale* produced only 33 t/ha, including 240 kg of nitrogen.

^{15}N Isotope-Dilution Technique

A preliminary pot experiment used six lines of millet grown in sand : vermiculite (1 : 1 w/w) in a greenhouse to explore (in a collaborative project with Rothamstead Experimental Station funded by the Overseas Development Administration, UK) the possibility of using the ^{15}N isotope-dilution principle to screen for potential to fix atmospheric nitrogen in the rhizosphere. Single plants in each pot filled with vermiculite were watered with 10 ppm nitrogen as potasium nitrate labelled with ^{15}N (10 atom% excess). Millet lines varied in ability to fix atmospheric nitrogen; 17% of total plant nitrogen uptake by line D 180 was derived from fixed nitrogen, compared with 0% by ICH 107 (Table 11). Considerable dilution of added ^{15}N was observed in all the lines; further experiments are in progress to determine the source of ^{14}N, which diluted the ^{15}N.

Nitrogen-fixing Bacteria

We compared different methods of estimating bacterial populations and isolating N_2-fixing bacteria from root or soil samples. Two nitrogen-free media that contained sucrose and malate as the carbon source were used to compare three methods of isolating and quantifying the bacteria. Counts of presumptive nitrogen fixers (4.5×10^8 in sucrose and 2.5×10^8 in malate media/g of root) were higher under the dilution and plating method than counts estimated by most probable number (MPN) method in semi-solid media (5×10^5 in sucrose and and 5×10^4/g root in malate medium, and higher than axenic plant tubes (5×10^5/g root). Recovery of

Table 11. Isotope dilution estimate of nitrogen fixation associated with pearl millet lines (average of eight replications).

Line	Shoot weight (g)	Total N (mg/plant)	Atom % ^{15}N excess	% N fixed related to ICH 107	N fixed in relation to ICH 107 (mg)
D 180	20.0	133	1.822	17	22
PHB 12	20.7	127	1.847	16	19
Zongo	17.8	112	1.884	14	15
IP 2787	21.0	135	1.944	11	14
DS 395	21.4	115	2.064	6	6
ICH 107	25.1	127	2.186	0	0
SE	±1.57	±6.2	±0.0864		
CV (%)	21	14	12		

Table 12. Grain yield of pearl millet hybrids inoculated with nitrogen-fixing bacteria during summer 1983[1].

	Grain yield (kg/ha)			
Culture	BJ 104	MBH 110	MEBH 23/81	Mean
A. lipoferum (I)[2]	1280	1570	1560	1470
A. lipoferum (ICM 1001)	1370	1620	1640	1550
A. chroococcum (ICM 2001)	1250	1500	1670	1470
NBRE	1390	1520	1480	1460
Control	1160	1650	1570	1460
SE		±65		±37
Mean	1290	1570	1590	
SE		±29		
CV(%)		16		

1. Mean of 13 replications. Net area harvested 9 m². The crop was top dressed with 16 kg N/ha. Each plot was inoculated twice with 2.5 liters of liquid inoculum prepared by suspending in 25 liters of tap water, a 70-g peat culture with viable bacterial count of 10^8/g of peat.
2. Culture obtained from Centre National de la Recherche Scientifique (CNRS) France.

nitrogenase-positive bacterial isolates was 43% higher with sucrose and 30% higher with malate by the MPN method. Recovery of N_2ase-positive bacteria isolates from MPN with axenic plants was 37% using sucrose and 17% with malate medium.

Responses to Inoculation with Nitrogen-fixing Bacteria

Nitrogen uptake data are now available from a 1982 field trial measuring grain yield responses to inoculation (ICRISAT Annual Report 1982, pp 88-89). In the same trial nitrogen uptake by WC-C 75 inoculated with *Azospirillum lipoferum* (ICM 1001) increased to 49.4 kg/ha compared with 36.3 kg/ha for the uninoculated control. Inoculating with nitrogen-fixing bacteria, except *A. brasilense* (SP 7), increased nitrogen uptake by three millet cultivars. Nitrogen contents of 1.32% and 1.30% in grains of IP 2787 inoculated with *Azotobacter chroococcum* (ICM 2001) or *A. lipoferum* (I) were observed compared with 1.27% for the uninoculated control. A N content of 1.30% was produced in grain of ICMS 7703 inoculated with Napier Bajra Root Extract (NBRE), a mixed culture. With other N_2-fixing cultures, it was 1.19 to 1.27% compared with 1.16% in the uninoculated control. Maximum N content of 1.33% in grains of WC-C 75 resulted when the plants were inoculated with *A. lipoferum* (ICM 1001).

In two field experiments during the summer and rainy seasons with the same three millet cultivars, inoculation increased BJ 104's grain yield. NBRE increased grain yields 19.3% during the postrainy and 25.7% during the rainy season (Tables 12 and 13). Increases in grain yield of BJ 104 inoculated with other N_2-fixing bacteria ranged from 7.0 to 17.5% and 12.0 to 19.6%, respectively, in the postrainy and rainy seasons.

Nitrogen content in grains of BJ 104 inocu-

Table 13. Grain yield of pearl millet cultivars inoculated with nitrogen-fixing bacteria, rainy season 1983[1].

	Grain yield (kg/ha)			
Culture	BJ 104	MBH 110	MEBH 23/81	Mean[1]
A. lipoferum (I)[2]	2890	2610	3120	2870
A. lipoferum (ICM 1001)	2910	2860	2890	2890
A. chroococcum (ICM 2001)	2720	3090	2860	2890
NBRE	3060	3040	3100	3070
Control	2430	2870	2890	2730
SE		±193		±111
Mean	2800	2890	2970	
SE		±86		
CV(%)		18		

1. Mean of 7 replications. Net area harvested 9 m², a basal rate of 20 kg N and 20 kg P_2O_5/ha was applied. Each plot was inoculated twice with 2.5 liters of liquid inoculum prepared by suspending in 25 liters of tap water, a 70 g peat culture with viable baterial count of 10^8/g of peat.
2. Culture obtained from CNRS, France.

Table 14. Genotype-dependent variation in mycorrhizal colonization of pearl millet grown at three field locations[1].

Genotype	Country of origin	VAM colonization (%)			
		Alfisol A[2]	Alfisol B[3]	Alfisol C[4]	Mean
IP 3277	India	15	11	51	25
IP 3476	India	13	20	49	27
IP 5781	Nigeria	16	32	39	29
IP 3595	India	22	10	56	30
IP 5150	Niger	24	30	35	30
IP 4382	India	15	22	56	31
IP 6891	Tanzania	25	32	40	32
IP 6045	Niger	21	33	41	32
IP 6114	Cameroon	25	28	49	34
IP 4807	India	23	28	57	36
IP 5427	Niger	26	27	56	36
IP 5335	Niger	22	33	55	37
WC-C75	India	17	23	73	38
IP 6590	Malawi	33	40	42	38
IP 6136	Cameroon	28	35	53	39
IP 4807	India	23	28	57	36
IP 4861	Lebanon	22	25	70	39
ICH 220	India	30	36	52	39
BJ 104	India	27	34	58	40
MBH 110	India	23	30	67	40
IP 5420	Niger	15	42	62	40
IP 3840	India	27	42	52	41
IP 3120	India	25	26	77	43
IP 5692	Nigeria	29	33	70	44
IP 5306	Niger	22	44	70	45
IP 5009	Nigeria	23	47	74	48
IP 5310	Niger	44	43	61	50
IP 4937	Uganda	30	50	66	48
IP 6538	Mali	33	41	74	50
IP 5140	Niger	37	49	77	54
IP 5921	Senegal	42	59	67	56
SE		±3.1	±4.4	±4.2	±2.1
CV(%)		24	12	14	18

1. Each value is a mean of 20 observations made from each of 4 replicate plots of 2 rows each 3 m long.
2. Alfisol A - Low fertility; not cultivated previous two seasons; 3.5 ppm Olsen's P.
3. Alfisol B - Low fertility; cultivated previous season; 5.0 ppm Olsen's P.
4. Alfisol C - High fertility; under long term cultivation; 20.0 ppm Olsen's P.

lated with *A. lipoferum* (ICM 1001) was 1.68% compared with 1.50% for the uninoculated control.

Variation in Ex-Bornu for Stimulating Rhizosphere Nitrogenase Activity

Large plant-to-plant variability in nitrogenase activity of Ex-Bornu plants has been observed with the intact-plant assays for pot-grown plants. To verify the variability, we grew 150 Ex-Bornu seeds from GRU, ICRISAT in a greenhouse and estimated nitrogenase activity by intact-plant assays. Variation was large, from 0-1900 nmoles C_2H_2/plant per hr. We are continuing selfing to obtain uniform high and low nitrogenase-stimulating lines from the Ex-Bornu population.

Mycorrhiza

Phosphorous Nutrition

We examined pearl millet's response to vesicular arbusclar mycorrhiza (VAM) inoculation, in sterilized and nonsterilized soil with various P fertilizer additions. In sterilized soil total dry matter produced by VAM-inoculated plants given 10 kg P/ha was equivalent to that produced by uninoculated plants given 20 kg P/ha. In nonsterilized soil, response to VAM at 0 and 5 kg P/ha was not significant. Evidently efficient VAM fungi are needed for significant responses in natural soil.

Genotype-Dependent Colonization

Three 1982-83 field trials examined VAM colonization by genotype, With 30 selected pearl millet genotypes grown at three Alfisol locations that differed in available phosphorus. Mean mycorrhizal colonization of the genotypes, across locations, varied from 25 to 56% (Table 14). VAM colonization percentages for locations A, B, and C were 13 to 42, 10 to 57 and 35 to 77. Overall, the genotypes tended to rank similarly for VAM colonization with certain exceptions. Genotypes that produced higher VAM colonization also gave more uniform rankings across the three locations.

In an experiment involving 2 ms lines, 5 pollen parents, and 9 hybrids developed by crossing pollen parents on the ms lines, the extent of VAM colonization varied widely in each group (Table 15), confirming genotypic dependence on VAM colonization. Although ms line 5141A registered significantly higher VAM colonization than ms line 111A, hybrids made on 5141A and those made on 111A did not differ in VAM colonization. 111A hybrids were more heterotic (positively) than 5141A hybrids, and low × low combinations exhibited highest heterosis for VAM colonization.

Table 15. Mycorrhizal colonization of parent genotypes and some selected crosses of pearl millet grown in natural field soil under greenhouse conditions.

Genotype		Colonization (%)[1]
Male-sterile parent		
5141A		51
111A		37
Crosses and male parent		
5141A	× 631 P 3	51
111A	× 631 P 3	57[2]
	631 P 3	37
5141A	× 733 P 1	41
111A	× 733 P 1	54[2]
	733 P 1	38
5141A	× 612 P 3	50
111A	× 612 P 3	50[2]
	612 P 3	65
5141A	× 623 P 2	44[2]
	623 P 2	56
5141A	× 612 P 1	66
111A	× 612 P 1	54
	612 P 1	63
SE		±4
CV (%)		15

1. Values are means from 3 replicate pots with one plant each.
2. Crosses showing significantly higher/lower colonization compared with both parents ($P < 0.05$).

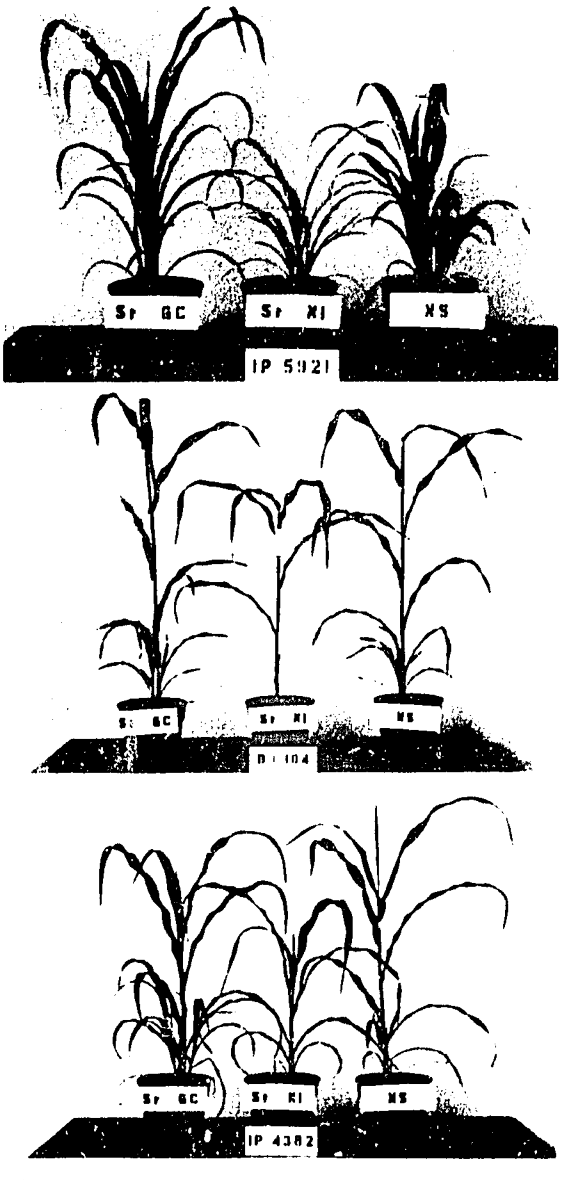


Figure 11. Differential growth in three pearl millet genotypes when grown: in sterile soil inoculated with *Gigaspora calospora* (St GC), in sterile soil without inoculation (St NI) and, in nonsterile soil containing natural VAM (NS).

Genotype-Dependent Growth Response

Using pot trials and 10 selected genotypes, we made detailed analyses of the relations between root growth (total length), total mycorrhizal root length, percentage VAM colonization, and growth and P uptake response to inoculation. Genotypes differed significantly ($P<0.05$) for VAM colonization percentages when challenged with a single-spore isolate of VAM fungus (*Gigaspora calospora*), and also in nonsterilized soil containing indigenous VAM fungi. Three of the genotypes (IP 5140, IP 4937, and MBH 110), each recorded significantly ($P<0.05$) different amounts of mycorrhizal root length but their total root lengths did not differ significantly. So both mycorrhizal infection and spread within the root system are genotype dependent. Since rapid maximum root colonization by the VAM fungi principally determines symbiosis efficiency, genotypes with high colonization are desirable.

Growth responses of genotypes also differed when inoculated with a single-spore isolate of VAM fungus (*Gigaspora calospora*) or a group of those found in soils (Fig. 11). Total mycorrhizal root length and colonization percentage correlated significantly with shoot dry matter ($r = 0.52$ and 0.50, respectively; $p < 0.01$) and total phosphorus uptake ($r = 0.46$ and 0.45, respectively; $p < 0.05$) but not with P concentration in the plant tissue.

Our pot tests with three West African cultivars also showed growth response and P uptake due to VAM inoculation are genotype dependent (Table 16). One cultivar, Zanfarwa, recorded large response to inoculation with *Gigaspora calospora*. Zanfarwa's P-uptake in sterilized soil was lowest when VAM was absent but highest of the tested cultivars with VAM. In nonsterilized soil, Zanfarwa and IP 5921 recorded significant increases in dry matter and P content due to VAM inoculation, but cultivar Sadoré local did not.

Plant Improvement

Source Material

Mobilizing genetic variability from unadapted germplasm into adapted breeding materials at ICRISAT Center led us to identify about 1700 F_4-F_8 progenies representing wide diversity for yield components, height, and maturity. Three groups of breeding lines (LCSN, F_4FC, S10B)

Table 16. Influence of mycorrhizal inoculation on growth and phosphorus uptake of three West African pearl millet lines[1].

		Shoot dry weight (g/plant)		Phosphorus uptake (mg/plant)		VAM colonization (%)	
Soil	Line[2]	M[3]	NM[3]	M	NM	M	NM
	IP 5921	6.91	4.74	16.3	13.0	48 c[4]	0
Sterilized	SDL	4.96	4.20	16.3	13.8	14 a	0
	ZAN	7.83	2.93	19.3	8.3	31 b	0
	IP 5921	5.53	4.73	15.2	14.3	78 d	44 bc
Nonsterilized	SDL	4.19	3.92	11.7	10.2	46 bc	35 bc
	ZAN	5.47	4.03	12.7	11.0	53 cd	52 cd
SE		±0.334		±0.81			
CV (%)		20		20		10	

1. Each value is a mean of 8 observations.
2. IP 5921 = Germplasm line from Senegal, SDL = Sadoré local (Niger), ZAN = Zanfarwa (Nigeria).
3. M = Inoculated with VAM (*Gigaspora calospora*). NM = Not inoculated.
4. Values with similar letters are not significantly different at $P < 0.05$; analyzed after $\text{Log}_{10}(x + 1)$ transformation.

and two dwarf composites (3/4 Ex-Bornu, 3/4 HK) originating from breeding programs in Africa are particularly promising in crosses. An advanced progeny selected directly from LCSN 72 is a promising restorer on an ICRISAT-developed, d_2 dwarf, ms line (81A) whose hybrid has done well in ICRISAT trials over 2 years and is being multiplied for test in the All India Coordinated Millet Improvement Project (AICMIP) trials.

Two experimental varieties made from a Togo population yielded up to 25% more than WC-C75 in the Initial Experimental Variety Trial (IEVT) 1983. Several Ghana accessions, phenotypically similar to Togo and probably of the same landrace type, are equally promising and represent a good source of earliness, large seeds, high yield potential, and perhaps higher protein content with varied seed color. Togo × Souna crosses have proved particularly promising in West African breeding programs.

In a population backcrossing program d_2 dwarf versions derived from the 3rd backcross of 7 tall composites (with GAM 73 as principal d_2 gene donor) were compared with their recurrent tall composites for 2 years at two locations (Table 17). The dwarf versions of the tall composites compared well in grain yield with their tall, recurrent composites. In Nigerian composite and Ex-Bornu, dwarf versions yielded slightly more than tall versions.

Hybrid Testing and Pollinator (R-line) Development

Forty-three crosses between pollinators were made during summer, and 50 F_2s and 26 BC_1F_1s were grown during the rainy season; 1630 F_3 lines were advanced to F_4 and 1624 F_5 lines to F_6. 1236 F_6 lines were evaluated for agronomic acceptability as possible pollen parents during the rainy season, 1983, for test crossing the next summer.

We evaluated 2104 test crosses in test-cross nurseries and selected 316 for evaluation in replicated trials. Of 390 hybrids evaluated in replicated trials during 1983, we selected 60 for evaluation in the next level of hybrid trials. From two of last year's initial hybrid trials 8 hybrids were chosen for further testing in the Pearl Millet Advanced Hybrid Trial (PMHT).

During 1983, hybrids ICH 451 [81A ×

Table 17. Performance of recurrent (tall) pearl millet composites and their d_2 dwarf versions derived after third backcross (based on three tests over 2 years).

Character	Height group	Composite[1]							Control[2]	SE
		EC	MC	WC	IVC	SSC	NC	EX-B		
Grain yield	Tall	2570	2440	2470	2510	2480	2480	2130		±87
(kg/ha)	Dwarf	2320	2550	2380	2480	2390	2700	2370	2110	
Plant height	Tall	193	206	203	215	220	240	248		±2.5
(cm)	Dwarf	144	144	140	148	147	167	163	140	±0.4
Ear length	Tall	23	25	24	26	26	32	30		±0.4
(cm)	Dwarf	25	28	26	29	27	33	33	32	
Days to	Tall	42	43	45	46	46	47	50		±0.3
50% bloom	Dwarf	42	44	47	46	47	49	50	45	

1. EC = Early Composite. MC = Medium Composite. WC = World Composite. IVC = Intervarietal Composite. SSC = Super Serere Composite. NC = Nigerian Composite. Ex-B = Ex-Bornu.
2. Control = GAM 73-K 77.

(LCSN72-1-2-1-1)] and ICMH 82205 [81A × (B Senegal 2-5 × 700651)] averaged 14 and 12% higher yields than the mean of three controls, ICMS 7703, WC-C75, and BJ 104, at seven locations (Table 18). Six hybrids (EICH 8301, EICH 8306, EICH 8309, EICH 8315, EICH 8316, and EICH 8317) were 25 to 30% superior in yield over controls in the Pearl Millet Elite Hybrid Trial (PMEHT) (Table 19).

Through our Uniform Progeny Nursery (UPN), the AICMIP parental trial, and individual seed requests, we sent 115 inbred lines and 3 pollinators to cooperating scientists in national programs.

Development and Improvement of Seed Parents

The seed parents project has identified, from 12 initial crosses, about 228 pairs of A and B lines

Table 18. Performance of pearl millet hybrids for grain yield (seven locations) and downy mildew incidence (in ICRISAT Center DM nursery) and two other agronomic traits in PMHT, rainy season 1983.

Entry	Pedigree	Source	Mean grain yld. (kg/ha)	Rank	% over mean of controls	DM (%) at ICRISAT Center	Days to 50% bloom	Plant height (cm)
ICH 451	81A × (LCSN 72-1-2-1-1)	ICRISAT	3020	2	114	0.0	53	219
ICMH 82205	81A × (B Senegal-2-5 × 700651)	ICRISAT	2970	3	112	0.0	56	224
Controls								
MBH 110	hybrid	MAHYCO[1]	3070	1		0.0	46	202
ICMS 7703	synthetic variety	ICRISAT	2740	9		0.5	52	227
WC-C75	experimental variety	ICRISAT	2580	13		0.0	51	218
BJ 104	5141A × J 104	AICMIP	1880	21		24.0[2]	47	173
SE			±240			0	±1.6	±11.2
Mean (21 entries)			2670			1.5	52	208

1. MAHYCO = Maharashtra Hybrid Seed Company.
2. HB 3 used as control.

Table 19. Performance of pearl millet hybrids for grain yield (three locations) and downy mildew incidence in ICRISAT Center DM nursery and two other agronomic traits in PMEHT, rainy season 1983.

Entry	Pedigree	Source	Mean grain yld. (kg/ha)	Rank	% over mean of controls	DM (%) at ICRISAT Center	Days to 50% bloom	Plant height (cm)
EICH 8301	5141A × [(T166-2 × 700594-2-6)-90]-7	ICRISAT	3560	4	127	0.0	49	198
EICH 8306	5141A × [(T166-2 × 700594-2-6)-90]-18	ICRISAT	3660	1	130	2.8	48	191
EICH 8315	5141A × [(NW-15-18)-44]-2-3	ICRISAT	3620	2	129	0.0	51	200
EICH 8317	5141A × [(NW-15-18)-44]-9-1	ICRISAT	3610	3	129	1.9	52	191
EICH 8309	5141A × [(T166-2 × 700594-2-6)-90]-28	ICRISAT	3540	5	126	0.0	48	187
EICH 8316	5141A × [(NW-15-18)-44]-6-1	ICRISAT	3500	6	125	2.3	51	200
Controls								
MBH 110	hybrid	MAHYCO	3190	16	114	0.0	43	195
ICMS 7703	synthetic variety	ICRISAT	3080	20		1.0	49	212
WC-C75	experimental variety	ICRISAT	3020	21	100	0.0	48	208
BJ 104	5141A × J 104	AICMIP	2340	23		45.3[1]	41	162
SE			±270				±0.7	±5.6
Mean (23 entries)			3290		3.0		49	195

[1] HB3 used as control.

(all in A_1 sterile cytoplasm) that are at various stages of backcrossing. They represent wide variability for plant height, maturity, ear length, and tillering. Three A lines (ICM 831A, 832A, 833A) from the 6th backcross stage of 81A × (J 1623 × 3/4 Ex-Bornu-96-1-10) were entered into the AICMIP A-lines nursery in the 1983 rainy season. While all showed resistance to DM and retained perfect male sterility, ICM 833A (relatively early-flowering) was consistently superior at several locations and has been advanced for further testing. ICM 832A being later, may be useful for hybrid programs in southern India.

Another ms line (ICM 834A) developed from Serere 10 bulk also was evaluated in 1983 in the AICMIP A-lines nursery. It was consistently selected at several locations and advanced for further testing. Less susceptible versions (DM 6%) of highly susceptible, but otherwise agronomically promising, ms lines (21A and 68A) from Kansas State University, USA were developed after 4 generations of intensive Plant(A) × Plant(B) crossing and selection in the DM nursery at ICRISAT Center. Preliminary testcross evaluations show that 21A, 68A, and especially S10A have good combining ability for early-maturing, large-seeded high yielding hybrids. Two sets of about 50 diverse variety-cross progenies were each crossed onto 81A (an ICRISAT developed ms line) and 5141A (the most extensively used ms line in Indian hybrid programs). Both trials were evaluated at ICRISAT Center and at Bhavanisagar; 81A hybrids yielded significantly more than 5141A hybrids in both trials and at both locations, with a greater superiority at Bhavanisagar than at ICRISAT Center (Table 20).

Variety Development

Intrapopulation recurrent selection aimed at improving pearl millet populations for grain yield, adaptability, and their potential for producing high yielding varieties is being conducted on 7 composite populations, on which 2 to 7 cycles of selections were completed by 1983. The selection systems now used are S_1 (2 years per cycle) with multilocation progeny performance testing, and modified half-sib (1 year per cycle), using phenotypic performance as the selection criterion.

Table 20. Grain yield (kg/ha) of pearl millet 81A hybrids and 5141A hybrids in two trials, 1983.

Trial	Hybrid group	Number of entries	ICRISAT Center		Bhavanisagar	
			Mean	Range	Mean	Range
I	5141A hybrids	52	3400	2400-4220	3510	1970-5190
	81A hybrids	52	3820	1870-4770	4730	2510-6070
SE			±33		±43	
II	5141A hybrids	48	3280	2400-4280	2270	1080-3380
	81A hybrids	48	3450	1540-4660	2780	2060-3790
SE			±32		±32	

Table 21. Genetic gains from recurrent selection for grain yield and downy mildew resistance in six pearl millet populations.

Name of population	Cycles of improvement	Grain yield (kg/ha)				DM (%)			
		Cycle		Gain (%)		Cycle		Gain (DM %)	
		C_0[1]	Latest	Total	Per cycle	C_0	Latest	Total	Per cycle
Super Serere Composite	5	1930	2110	+9.3	1.9	2.14	0.96	-1.18	-0.24
Medium Composite	5	1880	2280	+21.3	4.3	4.17	3.14	-1.56	-0.31
Intervarietal Composite	4	2110	2390	+13.3	3.3	1.93	1.56	-0.37	-0.09
New Elite Composite	3	2360	2570	+8.9	2.9	1.36	0.00	-1.36	-0.45
Early Composite	4	1890	2260	19.6	4.9	5.59	4.61	-0.98	-0.25
D_2 Composite	2	1970	2270	15.2	7.6	7.47	4.92	-2.55	-1.28

1. C_0 = Base population.

Table 22. Mean performance of selected experimental and progeny varieties trial in Advanced Population Varieties Trial (APVT), 1982 and International Pearl Millet Adaptation Trial (IPMAT), 1983.

Entry	Grain yield (kg/ha)						Days to 50% bloom		DM (%)
	APVT 1982			IPMAT 1983					
	Mean[1]	Rank	% of WC-C75	Mean[2]	Rank	% of WC-C75	APVT 1982	IPMAT 1983	APVT 1982
IVC-P8004	2630	5	108	2200	2	111	49	50	4
IVC-P8001	2550	11	105	2200	3	111	51	51	0
MC 81121	2630	6	108	2030	11	102	47	50	5
IVC 80135	2750	1	113	2010	13	102	52	54	4
WC-C75 (control)	2426	18		1980	15		48	50	2
Test entries	24			22			24	22	24
SE (Mean)	±91			±70			±0.4	±0.3	-

1. Over four locations.
2. Over ten locations.
3. Data from ICRISAT DM nursery.

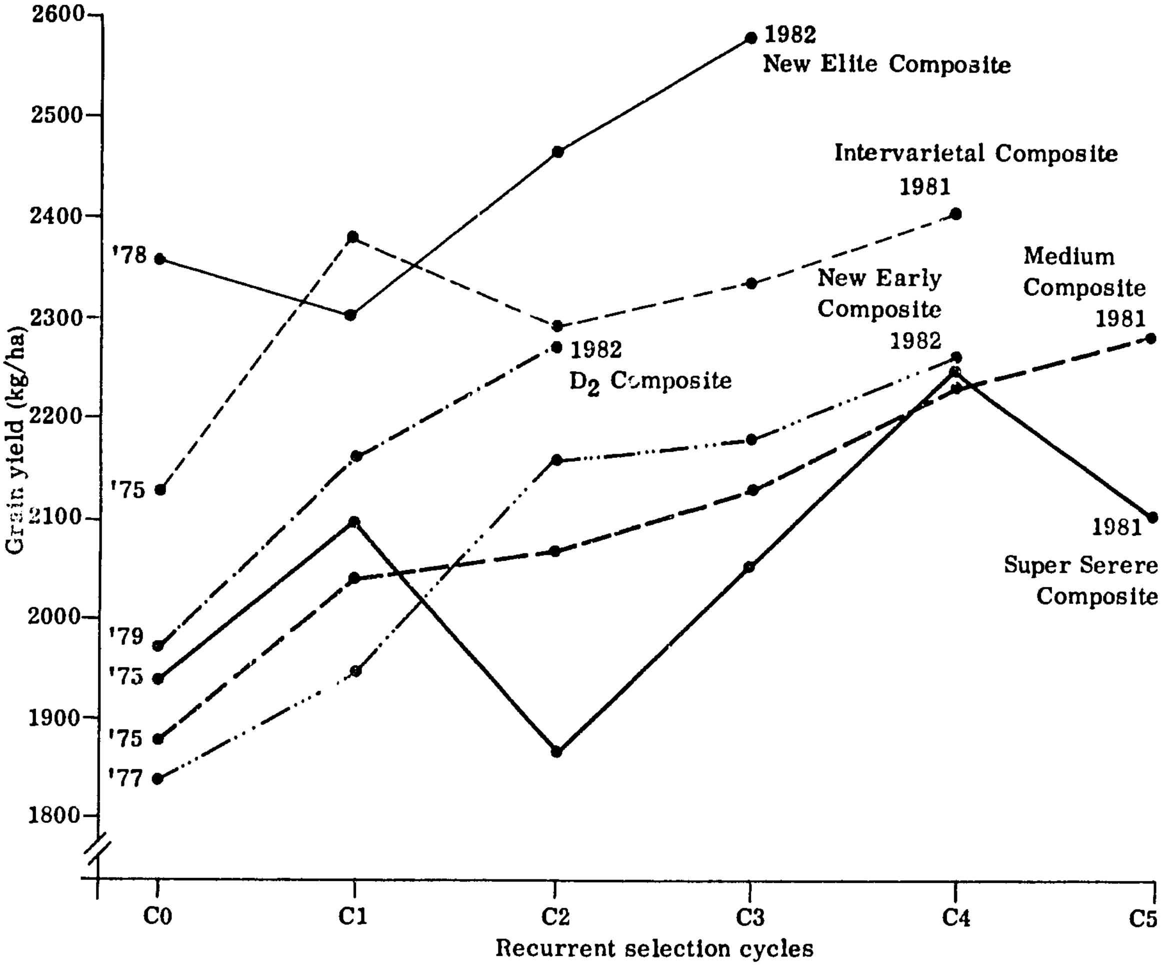


Figure 12. Gain in grain yield in six pearl millet composite populations in composite bulks test, three locations, 1983.

Improvement in Populations

Recurrent selection has been effective in changing gene frequencies positively for grain yield, disease resistance, and other important agronomic characters. For grain yield, genetic gains have been from 1.9 to 5.0% per cycle. Resistance to DM in all composites and to smut in the smut-resistant composite have increased substantially, with plant height and maturity unchanged (Table 21 and Fig. 12).

Development of Superior Varieties

Gradual improvement of populations has led to the development of high yielding, disease-resistant varieties in successive cycles. IVC 80135, IVC-P 8004, and MC 81121, 3 varieties developed in 1981, outyielded WC-C75 in all tests in 1981 to 1983 (Table 22). Similarly, of 33 varieties developed in 1982 and tested in 1983, ICMV 82111, 82113, 82116, 82117, 82131, and 82132 outyielded WC-C75 in 1982 and 1983 (Table 23). The last two varieties, ICMV 82131 and 82132, are resistant to both DM and smut.

Synthetic Development

Elite inbreds and partial inbreds from variety crosses (many between parents of successful synthetics, source material lines, and population

Table 23. Mean performance of selected experimental pearl millet varieties in initial (IEVT), 1982 and advanced (APVT), 1983 trials.

	Grain yield (kg/ha)								
	IEVT 1982			APVT 1983			Days to 50% bloom		DM (%)
Entry	Mean[1]	Rank	% of WC-C75	Mean	Rank	% of WC-C75	IEVT 1982	APVT 1983	IEVT 1982
ICMV 82116	2170	11	108	2910	1	115	52	54	0.0
ICMV 82117	2280	4	113	2840	2	112	57	56	6.4
ICMV 82113	2240	6	111	2800	3	110	53	53	0.7
ICMV 82111	2200	9	109	2800	4	110	53	54	0.0
ICMV 82131	2310	2	115	2760	5	109	54	55	2.0
ICMV 82132	2200	8	109	2730	9	108	52	54	1.9
WC-C75 (control)	2010	30		2530	17		53	50	2.9
Test entries	36			25			36	25	36
SE (Mean)	±92			±100			±0.6	±0.4	-

1. Mean based on four test locations.
2. Data from ICRISAT DM nursery.

progenies) are used in developing synthetics. Special synthetics have been made from disease-resistant lines. Two stages of selection are used to create potential parents of synthetic: inbred lines are selected for crossing, and partially-inbred progeny are then selected from these crosses. Selection is for yield, disease resistance, and other phenotypic characters such as plant height, bristles, and maturity. The partially-inbred progeny are then selected as parents of synthetics on the basis of their combining ability assessed by diallel techniques.

During 1983, more than 600 F_1s, 300 F_2s, and 2000 F_3 to F_5 progenies and 500 inbreds were planted; 75 inbreds were tested multilocationally in five diallel combination groups, and 54 and 22 synthetics were tested, respectively, in initial and advanced synthetic trials.

Among the synthetics tested during 1983 in the Pearl Millet Advanced Synthetic Trial (PMST), ICMS 8282 and 8283, developed from smut-resistant lines, were among the top yielders with a grain yield of 2500 kg/ha or more. Their smut resistance was effective both at ICRISAT Center and under field conditions in Niger and Senegal.

Synthetics developed in this project and contributed to AICMIP continued to be high yielding (Table 24) and ICMS 7703, after 6 years of rigorous testing at 27 locations, is being considered for release in India. Another synthetic, ICMS 7704, after 3 years of similar testing, was identified for the national minikit program for 1984 and 1985. Other promising synthetics in AICMIP tests in 1983 were ICMS 7818, 7835, 7857, and 8021.

International Testing

The 8th International Pearl Millet Adaptation Trial (IPMAT) consisted of 7 hybrids, 2 population composite varieties, 7 synthetics, and 5 experimental varieties tested at 21 locations in 3 southern Asian countries and Niger. Since 1979, when the African Regional Trial was initiated, distribution has been slowly reduced to African countries. Results from 15 locations in 3 countries indicated that hybrid ICH 448, with 1879 kg/ha grain yield, was the top entry followed by IVC-P8004 (1874 kg/ha) and ICMS 8010 (1848 kg/ha).

Seventeen varieties, hybrids, and hybrid-pollen parents from ICRISAT were included in various AICMIP trials in 1983.

The International Pearl Millet Observation Nursery (IPON), initiated during 1981, was revised with new experimental varieties and synthetics (IVS 5454, ICMS 7885, and NELC-H79) and we continued to despatch it in response to various requests. Our close involvement with ICRISAT Sahelian Center, Niger continued this year. Besides furnishing specific classes of breeding material, we supplied one set of all major trials.

Forty Indian pearl millet scientists participated in Millet Field Days at Bhavanisagar, Hissar, Ludhiana, and ICRISAT Center. (At ICRISAT Center there were two Field Days including a Summer Field Day for Andhra Pradesh Agricultural University (APAU) scientists.) Most of them requested specific entries from our breeding/pathology nurseries, and we provided more than 4100 seed samples. In addition to those requests, our regular trials and nurseries (now published in booklet form in March every year) continued to be a source of genetic material for cooperators' programs. Our nurseries, UPN, are now requested by nearly 20 cooperators in India, while IPON is requested mostly by scientists where millet is a new crop. IPMAT, comprising material mainly from ICRISAT Center and cooperators in India (but also other countries) is restricted to southern Asian countries, while a similar trial, ICRISAT Pearl Millet African Zone A Trial (IMZAT), is organized from the Sahelian Center, for cooperators in Africa.

A significant step in distribution was initiating the ICRISAT-SADCC Pearl Millet Nursery (PMN) and Pearl Millet Variety Observation (PMVO) nurseries for southern African countries. Additionally, 420 seed samples covering trials, nurseries, and male steriles were supplied to Zambia where varieties and hybrids from ICRISAT Center were previously found to be adapted.

Grain Quality

High Protein Lines

Pedigree selection for high grain protein for six generations has resulted in identifying 440 S$_6$

Table 24. Yield performance of ICRISAT pearl millet entries in AICMIP trials, 1982.

			ICRISAT entry				Top-yielding entry	
Trial	No. of locations	No. of entries	Entry	Grain yield (kg/ha)	Rank	Trial mean (kg/ha)	Entry	Grain yield (kg/ha)
Initial Hybrid Trial-I	18	22	ICH 440	2450	6	2200	MBH 136	2620
Advanced Hybrid Trial-II	28	21	ICH 241	2360	11	2330	MH 115	3350
			ICH 220	2220	13			
Initial Population Trial-IV	15	16	IVS-P78	2000	1	1820	IVS-P78	2000
			D$_1$C-P7904	1890	6			
			ICMS 7857	1880	8			
Advanced Population Trial-V	22	18	IVS 5454	1800	13	1890	ICMS 7703	1890
			IVS-P77	1820	10			
			ICMS 7835	1830	9			
			ICMS 7704	1860	6			
			NELC-P79	1870	4			
			ICMS 7818	1880	3			
			ICMS 7703	1890	1			

Breeding work initiated at ICRISAT Center several years ago has led to pearl millet ICMS 7704 (above) being identified for minikit trials in India. WC-C75 (now known as ICMV 1) has already been released to farmers in India and one other ICRISAT line, ICMS 7703, is just a step short of release.

progenies, with 14.0 to 23.3% grain protein, from 15 of 30 originally selected genotypes. Progenies from four genotypes (700112, IP 2702, WC 190, and B 816) are stable for protein content. Selection and development of other lines from new sources of high protein are continuing.

High Protein Hybrids

Previous investigations of grain yield and protein relationships indicated that in pearl millet, unlike other cereals, the relationship is usually negative but weak (non-significant, r = -0.50 to 0.16), which offers possibilities for simultaneously selecting for increased protein and grain yield. Crosses between lines selected for high protein have produced F_1s with both high grain protein and yield. Eighteen F_1s showed 14.1 to 15.8% grain protein and 5 of them yielded as well as BJ 104 which has a normal grain protein level of 11.7%. Similarly, in a test of hybrids made by crossing high protein lines with male steriles (which have normal protein levels), 32 hybrids showed 14.0 to 15.8% grain protein and many of them yielded as well as BJ 104. All crosses of high protein lines between themselves, or with male steriles, do not produce high protein hybrids. The protein content of such hybrids, like yield, appears to depend on specific combinations.

International Cooperation

ICRISAT Sahelian Center

Diseases

The long range objectives of the millet pathology program is the identification and exploitation of resistance to downy mildew, ergot, and smut. To date, efforts have focused on development and/or adaptation of field screening techniques which are effective at the ISC. An attempt is also being made to establish areas of high *Striga hermonthica* infestation for possible future *Striga* resistance screening at the ISC. Surveys of diseases in farmers' fields in Niger and other countries in West Africa are also being undertaken. Nurseries planted at the ISC for disease evaluation are listed in Table 25.

Table 25. Material planted in the pathology program at ICRISAT Sahelian Center, Niger, 1983.

Nursery/ Collection	Source	Number of entries
IPMDMN	ICRISAT Center	50
IPMSN	ICRISAT Center	34
IPMEN	ICRISAT Center	32
IMZAT	Maradi	16
IMDN	ICRISAT Center	20
Sundaram 1(1982)	Samaru	31
Sundaram 2(1983)	Samaru	95
Total		278

Downy mildew (*Sclerospora graminicola*). The DM field research in 1983 was continued at Sadoré in a DM sick-plot area initially used in 1982. Although crop establishment and plant growth were generally good, the level of disease pressure was too low to evaluate for resistance.

The infector row technique used at ICRISAT Center was employed using sprinkler irrigation. Infector rows were planted early with either the ultra-susceptible line 7042 or a mixture of susceptible materials of West African and Indian origin. Infector row seed was dusted with oospores before planting and some plants were cut back to encourage new growth and production of sporangia. Infector rows did not produce the sporangia required to create disease pressure until seven weeks after planting, although plants of 7042 showed yellowing considerably earlier than this, suggesting possible earlier DM infection. After sporangial production was initiated in 7042, it increased rapidly and almost all these plants died prematurely. Infector rows planted with the mixture of susceptible materials developed very little DM, and relatively few plants within the test rows developed DM symptoms. Sporangial production was never profuse.

The reason for the general lack of DM is not known with certainty; however, the initial appearance of sporulation on 7042 coincided with a drop in maximum daily temperature below 35°C. It is believed that high temperature likely inhibited production of sporangia in infector rows, which in turn lead to a reduced incidence of disease in the nursery. Sprinkler irrigation was operated each evening, and several times on some days.

In a separate test, treating seed of Sadoré local at planting with oospores, collected during the previous season, did not significantly increase the level of DM over the nontreated control. Also, the fungicides Ridomil® and Aliette® used as seed treatments at standard and twice-standard levels had no significant effect on the DM incidence or severity. Overall DM incidence in this experiment was 9.1% for Sadoré local and 47.6% for NHB 3.

Attempts to improve DM resistance levels in two millets commonly grown by farmers in Niger, Sadoré local and Zenfarwa, were unsuccessful due to insufficient disease pressure; however, because the infection level was over 90% in one block of 7042, seed was collected from 50 DM-free plants for possible future use.

Smut (*Tolyposporium penicillariae*). The IPMSN was grown at Sadoré and inoculated by standard techniques. Twice the normal quantity of seed was sown, but plant establishment and growth were poor. Smut here and in the Samaru collections of Nigerian varieties was markedly lower than at Samaru or Kano. Plant establishment was exceptionally poor in the nursery.

Ergot (*Claviceps fusiformis*). Ergot-susceptible material was planted before the main season both in a screenhouse, where it was subjected to hourly water sprays, and in the field. Inoculation by standard techniques with sclerotial material collected in 1982 produced no infection. Moderate natural infection developed in the experimetal fields and provided inoculum for extensive inoculations, but the availability of this inoculum was too late for most of the experimental material.

Bacterial streak. Symptoms of an apparent bacterial disease at Sadoré in 1981 were absent in 1982 but widespread on the research farm and elsewhere in the district in 1983, perhaps as a result of abundant rainfall.

The symptoms are similar to those of bacterial streak of sorghum. Specimens were sent to the Commonwealth Mycological Institute, London for isolation and identification of the causal organism, which has been presumptively identified as *Xanthomonas campestris* pv *holcicola*.

While this is an interesting new record for pearl millet, it is unlikely that the disease is new. Limited observations suggest that it may be distributed throughout the millet regions of West Africa, but the damage observed was insignificant.

Zonate leaf spot (*Gloeocercospora* sp). Zonate leaf spot was very common at Sadoré in 1983, probably as a result of the wet season. It appeared later in the season than bacterial streak whose lesions are often confused with leaf spot lesions. Damage was probably insignificant.

Another leaf spot, similar to zonate leaf spot but caused by *Dactuliophora* sp was observed in some wetter areas of West Africa, but not at Sadoré.

Surveys. Areas surveyed for disease were around Niamey and Gaya in Niger, along the Niamey-Ouagadougou road, and around Ouagadougou in Upper Volta.

Levels of all major diseases were low with negligible losses in the Niamey area. Fields with exceptionally high levels of DM in 1981 were totally free of disease in 1982 and/or 1983, confirming the opinion that the incidence of this disease can vary considerably from year to year and field to field.

Downy mildew levels were higher at Gaya, the southernmost point in Niger, and between Fada N'Gourma and Koupela in Upper Volta, than at the more northerly locations observed.

Smut and ergot were generally low, and rarely if ever serious. Ergot was commoner in the Niamey area in 1983 than in the previous two years, presumably because of above-average rainfall up to the end of the season.

Looking ahead. Research efforts will continue to focus on the establishment of effective disease screening nurseries. Knowledge gained from surveys and generally unsuccessful attempts at screening during the past three years should be useful.

Striga

Two fields at Sadoré, each about 1 ha and previously selected for heavy *Striga hermonthica* infestations, were sown (80 × 80 cm spacing) with local millet, except Ex-Bornu was planted on every 10th row. Millet inflorescences of *Striga* saved from 1982 were added to the seed in the planting holes.

Infestation was patchy in one of the plots, but it was sufficiently heavy in parts of the other to possibly justify trials on a limited scale in 1984.

Insect Pests

Activities in 1983 were aimed at identifying areas of consistently severe pest infestation and at documenting the incidence of the two major pests, *Raghuva albipunctella* and *Acigona ignefusalis*, in Niger. The major thrust of the entomology program resides, however, in developing alternate methods of pest control which involve either minimal or no use of insecticides. Towards this goal, several millet entries were evaluated for reaction to natural pest infestations. Cultural practices involving crop associations and crop-residue removal were also studied.

Incidence and distribution. The incidence of the earhead caterpillar, *R. albipunctella*, and the stem borer, *A. ignefusalis* were assessed by sampling farmers' crops in 203 locations across the millet-growing region of Niger. A separate survey conducted on the research station was aimed at developing a record of the annual pest situation there and its evolution in time.

Survey in Niger. The severest *Raghuva* infestations were recorded in the Fillinque area in the eastern part of the Niamey Department and near Makameye and Magaria in the southern part of Zinder Department. The lowest infestations were observed in the Dosso, southern Niamey, eastern Tahoua, and northern Zinder Departments (Fig. 13).

Acigona was recorded in all millet-growing locations in Niger. The most severely infested fields were found in the southern part of Dosso Department, the Fillinqué area of Niamey Department, and in the Magaria and Matameye areas in southern Zinder Department (Fig.14).

Situation at ISC. Severity of *Raghuva*, and *Acigona* infestations varied on the ISC research farm. *Raghuva* infestations were especially severe in two research blocks that contained early-maturing ICRISAT Center material and in a third block where BJ 104 and 7042 were cultivated. *Acigona* was most devastating in a research block sown under irrigation in late May. This infestation later spread to six other research blocks.

Population dynamics. Results from light-trap studies of adult moths were unreliable; however, data collected from stem borer infestation

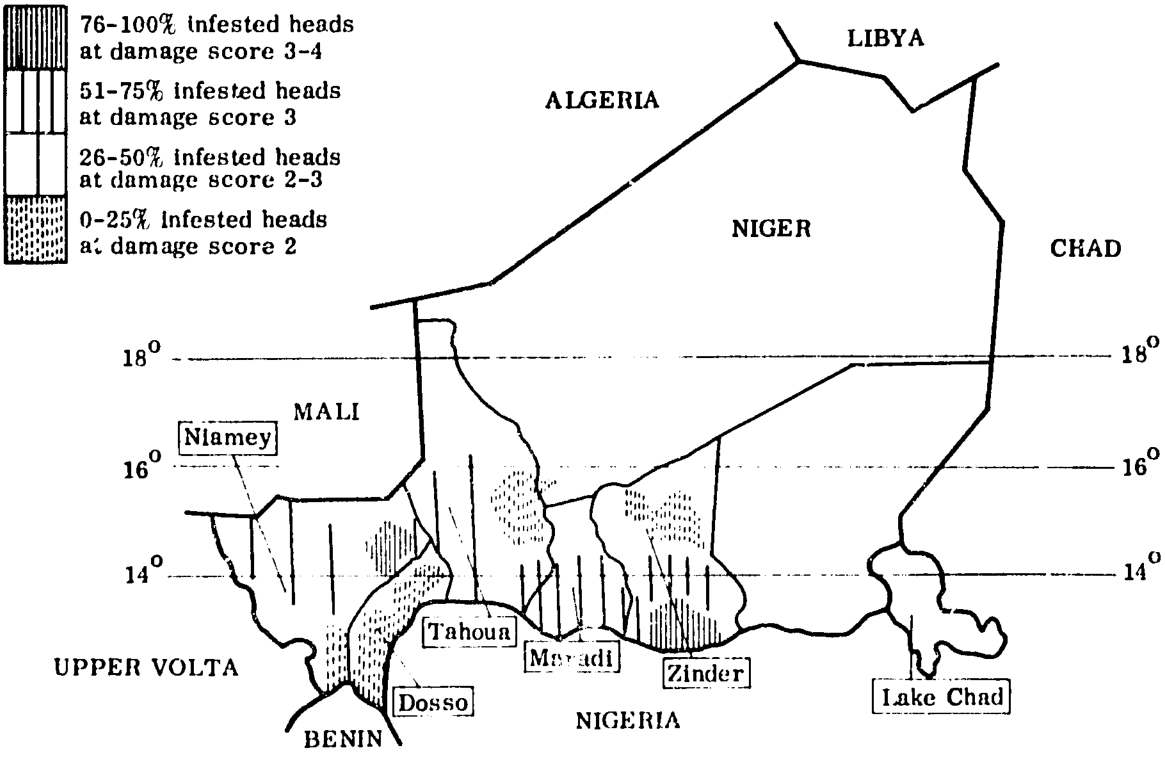


Figure 13. Distribution of the millet earhead caterpillar, *Raghuva albipunctella*, in five Departments of Niger, 1983.

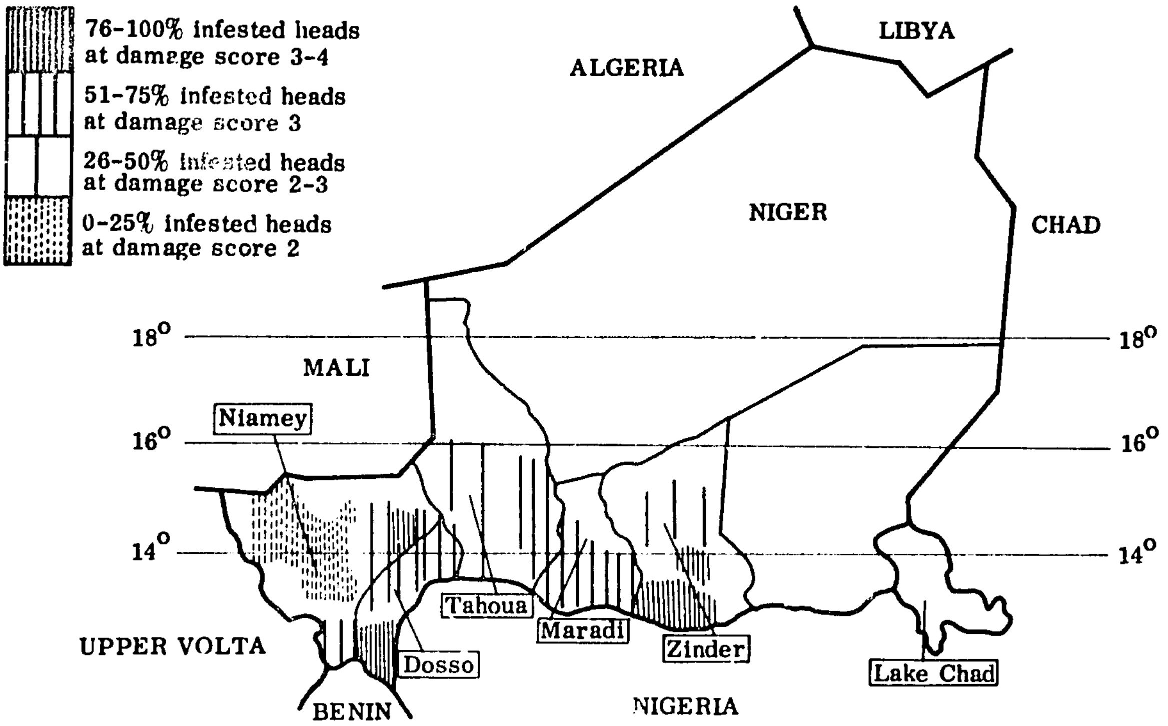


Figure 14. Distribution of the millet stem borer, *Acigona ignefusalis*, in five Departments of Niger, 1983.

assessments and weekly larval counts indicated two peaks at Sadoré, one in late July and the other in early September.

Using 20 × 65 m field blocks containing millet residue from the 1982 season, it was found in 1983 that retention of crop residue in the field during the long dry season resulted in higher early borer infestations, as diapausing larvae survived in millet stalks. No differences in reaction were observed among the three varieties of millet tested: HKP, CIVT and Sadoré local.

Reactions of millet entries to *Raghuva* and *Acigona*. More than 150 entries in eight trials of the ISC breeding program were evaluated for their reaction to *Raghuva*. ICRISAT Center materials, though less susceptible than the recommended CIVT, were generally more susceptible than the local entries (Sadoré, Toriniou, and Hainei Kirei) or material from African × African crosses. Five entries, IBMV 8302, INMG 1-1, INMG 52, ITV 8001, and Souna (Mali), were retained for further evaluation.

We evaluated 68 entries from the ICRISAT / IAR Samaru program in a field uniformly and heavily infested by *Acigona*, and selected INMB 106, INMB 218, and INMB 155 for further evaluation (Table 26). Sadoré local tillered continuously, providing continuous availability of stalk tissue for borer infestation.

Cropping entomology. Agronomy trials at ISC showed that the local cowpea variety as a monocrop was more susceptible to leafhopper (*Empoasca* sp) damage but less susceptible to thrips (*Thrips* sp) than other varieties. When the local cowpea was intercropped in alternate rows with millet, however, leafhopper numbers per plant fell 50%. Varieties Mougne and IT82 E60 were the most susceptible to thrips damage, and intercropping did not reduce the damage.

Fertilizer applied at the rate of 20 kg P_2O_5/ha as SSP and 36 kg N/ha as urea to sole cropped cowpea resulted in a doubling of the leafhopper infestation per plant, but reduced infestation by thrips.

Looking ahead. Incidence and distribution studies of both millet pests will be continued in 1984 to assess consistency in the areas identified as hot spots in Niger. Comprehensive pest distribution maps for each species will be developed for Upper Volta and Niger.

Stem borer infested plots will be developed and maintained by early planting under irrigation and by retaining crop residues. A large collection of pearl millet will be evaluated.

In 1984 we will initiate contacts with the Commonwealth Institute of Biological Control (CIBC), to survey and collect natural enemies of *Acigona* and *Raghuva*, in an initial step toward understanding how biocontrol agents have reduced *Raghuva* infestations in recent years.

Two trials designed to generate preliminary data on crop losses caused by *Raghuva* and *Acigona* had to be abandoned in 1983, after poor seedling establishment and sand blasting. They will be repeated in 1984.

Breeding

Our main objective is to generate improved, adapted parental material, and varieties for use by millet breeders working in the region. We have conducted research in germplasm evaluation and use, intrapopulation improvement, and development of seed parents and hybrids, and have cooperated in regional and international programs. Breeding research is carried on jointly with the pathologist, entomologist, and agronomist at ICRISAT Sahelian Center, and with the millet scientists at ICRISAT Center, in the ICRISAT West Africa program, and in national programs.

Germplasm evaluation and utilization. During the year we reevaluated 389 accessions, mostly from West Africa, and completed primary evaluation of 34 accessions of the Souna landrace from Senegal and from the 6th and 7th regions of Mali. From the 423 accessions we identified 39 as potential parents for the breeding program.

We have evaluated more than 1800 entries representing breeding material at various stages of development (F_1s, F_2 populations, F_3 and F_4 progenies, backcross F_2 populations and F_3 progenies, and inbreds). These entries originated from African × African crosses at ICRISAT Center and were obtained from programs in Mali, Niger, or Senegal, or were generated at the Sahelian Center in 1982. Two general conclusions were drawn from the evaluations:

1. Materials generated at ICRISAT Center as F_1s or F_2 populations contain useful segre-

Table 26. Entries identified as better performers in the ICRISAT/IAR Samaru stem borer evaluation, Sadoré, 1983.

Entry	Pedigree	Infested tillers (%)[1]	Infested stems (%)	Bored internodes (%)
INMB 106	S_1EVAL 88	10.0	6.7	2.2
INMB 218	$VC_2F_2(21)137\text{-}3$	20.1	26.7	19.5
INMB 155	$VC_2F_2(21)149\text{-}1$	15.4	28.3	17.1
Controls				
CIVT		15.4	73.3	45.3
Sadoré local		25.8	55.0	20.4
SE		±5.9	±19.0	±15.7
Mean		13.8	71.2	41.4

[1] 35 days after planting.

gants; but more advanced generations and inbreds from India have limited value. Backcrossing the F_1 to the adapted (African) parent improves the chances of recovering material of agronomic value.

2. Only crosses from parents of African origin, with the maturity and tolerance to biological and physical stresses of locally adapted varieties, perform well.

We have made nearly 1900 individual plant selections from these materials and have identified promising F_2 populations for making synthetics.

Farmers' fields in West Africa commonly have many intermediate forms between wild and cultivated subspecies of pearl millet, called shibras, whose vegetative and floral morphologies resemble pearl millet's but which reduce crop yields as they produce little harvestable grain. In field experiments to assess losses caused by shibras it was found that each 1% increase in shibras resulted in a 1% loss in grain yield (Table 27).

Population improvement. We conducted a 16-entry composite bulks trial to evaluate gene-pools produced by the ICRISAT/INRAN (Institut National du Recherches Agronomiques du Niger) program at Maradi and to identify composites for recurrent selection at the Sahelian Center. We selected two gene-pools, INMG 2-1 (with medium long head) and INMG 5-1 (with head girth) based on variability in plant height, head length, and maturity for further development.

We evaluated 140 S_1 progenies of Sadoré local, hoping to clean the local population of shibras (mean 5.7%, range 0 to 36.8%, recorded in half-sib testing during 1982) and DM (mean 10.4%, range 0 to 58.3%). Unfortunately DM disease pressure was low and very late in the season. S_1 progeny selection, however, proved to be more effective than half-sib selection for the elimination of shibras. Shibras were absent in 73% of the S_1 progenies compared to 42% of the half-sib program (Table 28).

Table 27. Yield losses caused by the presence of different proportions of shibras in two improved varieties.

Planted shibra frequency[1] (%)	Observed shibra frequency (%) and grain yield (kg/ha)					
	CIVT		P3 Kolo		Mean	
	(%)	kg/ha	(%)	kg/ha	(%)	kg/ha
50	41.7	657	42.3	588	42.0	623
33.3	27.3	876	29.6	686	28.6	781
25	18.8	872	22.4	926	20.6	899
12.5	11.3	989	9.6	1005	10.5	997
4.1	3.8	955	4.3	1092	4.1	1024
0.	1.0	1019	2.1	1068	1.6	1044
Mean	17.3	895	18.5	894	17.9	895

1. For grain yield:
The SE for two varietal means is ±47.91
The SE to compare levels of weed form frequencies at the same level of variety is ±131.62
The SE to compare variety means at the same level of weed form treatment or different levels of weed form treatment is ±135.07
The SE for 2 weedy form treatment means is ±93.02

Table 28. Frequency of shibras in half-sibs and S_1 progenies of the Sadoré local millet variety, 1983.

Shibras frequency	Number of progenies	% of total
Shibras present in both progenies	23	16
Shibras present in S_1 progenies only	15	11
Shibras present in half-sib progenies only	57	41
Shibras absent in both progenies	45	32
Total	140	100

Breeding seed parents. We have evaluated 209 A (male-sterile) and their corresponding B lines (maintainer lines) in different backcross stages, from six geographic areas of West Africa. The backcrosses were successful: we generated more than 300 A and B pairs for evaluation and another backcross. We identified 3/4 Hainei-Kirei and Souna to the best adapted source and more emphasis will be placed on these in future.

Cooking quality. Preliminary evaluation of 12 varieties (relative to Sadoré local) for *haourou* (a common food prepared from pearl millet in the region) quality indicated no gross differences in acceptability, although endosperm type and grain color of some of the lines differed from that of the local. Grain color following dehulling seemed to have little effect on flour color. There were, however, differences in ease of dehulling. Varieties K 13, Fakiyabad, and Mossi local were easy to dehull but DSA 74, BJ 104, and Togo were very difficult, suggesting hard endosperm types are easier to dehull. Bran accounted for 8 to 16% of grain weight giving mean flour recovery of approximately 85%. Slight differences were observed in color, texture, aroma, mouthfeel, and after-taste of products, but not in taste itself, indicating that taste score may not be a very significant component of the overall evaluation and that its assessment may be confounded by color and texture differences.

International and regional cooperation. This area of work involves yield trials, exchange nurseries, evaluation of breeding material originating from ICRISAT Center or from ICRISAT and national breeders in West Africa, and assistance with off-season nurseries and seed multiplication.

We planted five replicated yield trials originating from ICRISAT Center. Though initial emergence was good, hill stands realized were unfortunately very low because hills became covered with sand following several sandstorms during the season. All entries were attacked in epidemic proportions by *Raghuva albipunctella*, as they were relatively early. The test entries performed poorly because they matured earlier than the local variety, and because they lacked resistance to the biological and physical stresses cited, as they were selected and bred where these stresses are not so harsh.

We conducted one regional trial (ICRISAT Pearl Millet African Zone A Trial), three advanced yield trials for the ICRISAT/IAR Program, and one trial organized by ICRISAT-INRAN to assess a system suitable to maintain variability in pearl millet populations. From the 49-entry Pearl Millet Exchange Nursery, 10 entries (1 from Sudan, 3 from Niger, and 6 from Senegal) were rated as good performers.

We have obtained breeding material and trials from all ICRISAT programs in West Africa and ICRISAT Center, and have chosen lines from programs in Senegal, Mali, and Niger for evaluation at ISC. Lines selected from our 1983 nurseries will be evaluated in Mali, Senegal, and ICRISAT Center in 1984.

Looking ahead. We would like to evaluate Mali and Senegalese germplasm to identify accessions for potential use as parents in crosses and to develop a working collection. We will continue to produce new elite breeding material and use selected progenies to form synthetics, as entries for composites, and as potential B lines. Material emerging from our breeding program will be organized into small nurseries for preliminary evaluation by breeders in the region.

Cooperative Programs

Niger

Breeding

The ICRISAT cooperative program to improve pearl millet in Niger aims to make a wide array of improved varieties and genotypes available to the national program, and to develop breeding methods to produce desirable genotypes and varieties.

Plant Improvement

For the Niger national program, we now have 709 pearl millet breeding lines and populations including materials from Botswana, Cameroon, Central African Republic, Ghana, India, Mali, Niger, Nigeria, Senegal, Togo, and Uganda.

None of this material was previously available in Niger.

Recombination generation bulks from four gene pools, and composites (mass selections) derived from the gene pools have been sent to various pearl millet improvement programs in Africa to help derive varieties suitable for their locations. Two recombination cycles were completed in gene pool 5 (INMG-5), where short, thick-headed genotypes from Mali and Niger and their crosses are being pooled.

Trials and nurseries. Several experimental varieties developed by our program have been evaluated in Niger and at similar locations in Africa. ITMV 8002 and ITMV 8004 were promising in various national and regional trials and will go into national demonstration and farmers' field trials in 1984. Both have also shown promise in Cameroon, Nigeria, and Sudan, where they are in national trials.

In the 1983 National Multilocation Trial 1, coordinated by Institute National Recherches Agronomique, Niger (INRAN) for areas where annual rainfall exceeds 400 mm, ITMV 8303, ITMV 8002, and ITMV 8001 yielded more than CIVT, a widely grown open-pollinated cultivar. In National Multilocation Trial 2, for drier areas, ITMV 8304 and ITMV 8004 yielded 13 and 12% better than HKP, the control.

IMZAT-83, designed for multilocation testing across countries in Africa, and coordinated by us with assistance from ICRISAT Center, was sent to 16 locations in 10 African countries. At Maradi, despite drought (222 mm rain) ITMV 8002 and ITMV 8004 yielded 20 and 14% more grain than CIVT. At Sadoré ITMV 8001 was the top yielder. ITMV 8001, 8004, 8303, and 8304 have been recommended for prerelease demonstration and multiplication to be coordinated by INRAN in 1984. 530 S_1s and S_2s derived from ITMV 8001, 8002, 8003, 8004, 8302, and 8304 will be evaluated at Sadoré and Maradi in 1984.

Looking ahead. Farmers in the Maradi area have shown interest in ITMV 8001 and ITMV 8304. One kg of seed of each variety was given to each of 50 farmers for evaluation. They will evaluate them with their local varieties in 1984. We will visit the farmers' fields near harvest to evaluate performance and record DM incidence, shibras, and *Striga* for comparisons with the farmers' local varieties.

The 120 promising inbreds, which are at F_5 to F_7 stage of inbreeding, will be crossed during the 1984 dry season with male steriles to develop hybrids and synthetics that will be evaluated during the 1984 rainy season.

Upper Volta

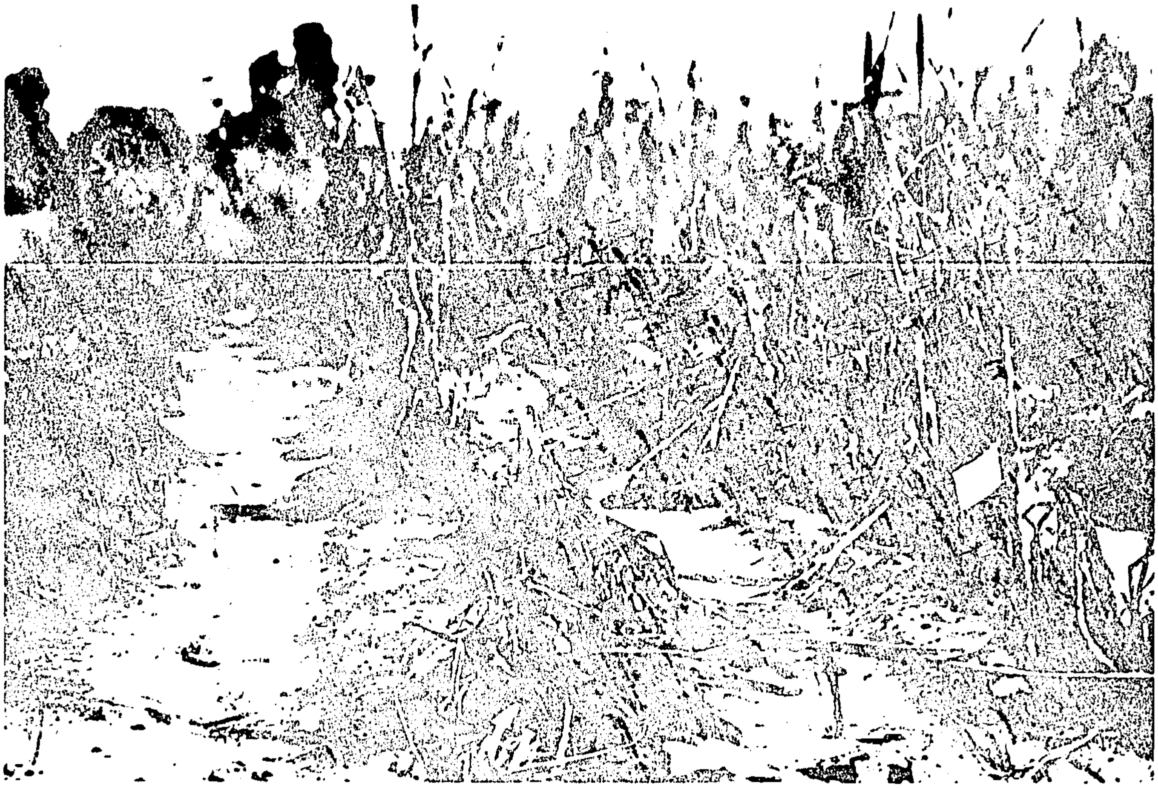
Breeding

Our objective is to develop varieties for the 500- to 900-mm rainfall zone with special emphasis on the Mossi Plateau, by selecting two groups of varieties with the following growth habits:

1. Photoperiod-sensitive, full-season varieties (about 140 days' maturity) that farmers can sow with the early rain (late May to 21 June) and that flower from 7 to 15 September, regardless of sowing date.
2. Photoperiod low-sensitive/insensitive early-maturing varieties (80 to 110 days) to be sown from late June to mid-July. They may also be useful for early sowing, when rains begin, as monocrops or intercrops with available superior early-maturing varieties.

Early-maturing varieties for late sowing. Multilocation trials to identify early-maturing varieties for late sowing condition continued. Trials sown in late June to 17 July at two locations. showed that two experimental varieties IKMV 8101 and IKMV 8201 consistently outyielded the photoperiod-sensitive local control (Table 29). Varieties IKMV 8101 and IKMV 8202 have acceptable *tô* quality. Both these varieties have performed well in various West African countries in IMZAT-83.

Results of research managed trials and other trials conducted in farmers' fields have not, however, shown a consistent yield superiority of the early-maturing entries. This is due to bird damage and in some cases due to flowering earlier



Two manifestations of drought, which emphasize the environmental stresses ICRISAT crops must endure: above, a devastated millet trial in Upper Volta; below, a farmers' field at Bema, Mali, which fared somewhat better.

Millet heads previously covered (right) show more grain than those left uncovered against damage by insects and loss of pollen in Upper Volta.

Table 29. Performance of two promising pearl millet entries and local control (grain yield, kg/ha) in Upper Volta, 1982 and 83.

	Kamboinsé		Ouahigouya	
	1982	1983[1]	1982	1983
IKMV 8101	1050(53)[2]	1280(50)	820(52)	320(62)
IKMV 8201	640(53)	1530(50)	970(51)	440(60)
Local control	390(60)	440(82)	580(64)	260[3]
SE	±70	±60	±90	±20

1. Average of trials sown on two dates.
2. Days taken to 50% flowering
3. Less than 50% flowering on 25 September.

than is normally expected. The research station trials were protected from birds at maturity, so significantly higher yields were obtained as compared to the late cultivars. Farmers' field trials were not only unprotected but also had a delayed harvest which aggravated the yield loss.

One might sow early-maturing varieties after 15 July to synchronize with the local variety. However, under season-end drought, varieties that flower earlier (but not in August to avoid pollen wash and insect damage) have an advantage over late-flowering varieties. Because the station's experimental plots become targets for all the birds in the vicinity, bird damage should be much less when early-maturing varieties are grown by several farmers in larger plots.

Mass selection in local cultivars. Of 395 S_1 lines, produced from selected heads of local cultivars and progeny tested, 24 showed good agronomic scores and retained low susceptibility to DM and smut. Of the selected lines, 18 flowered the first half of September regardless of the date planted, and 6 flowered between 21 and 31 August. Recombination was carried out in each group separately to derive relatively early (82/83 RPE 1 and 82/83 RPE 2) and late (82/83 RPL 1, 82/83 RPL 2) populations. Recombined populations were derived by using remnant S_1 or S_2 seeds.

The recombined populations, base populations (BP), and control entries were evaluated in seven environments and three locations with various seeding dates and management. Because of severe drought, results could be analyzed from only three environments, Kamboinsé, Ouahigouya, and Saria. Compared with the early recombined populations, the late populations performed better at Kamboinsé and Saria (750 to 850 mm rainfall zone). The opposite was true at Ouahigouya in the zone with lower rainfall (600 mm). Such location × entry interaction resulted largely from the effects of pollen wash and insect and bird damage on early-maturing entries (Kamboinsé and Saria) or drought on late-maturing entries (Ouahigouya). At Ouahigouya, average grain yield of 82/83 RPE 1 and RPE 2 surpassed the yield of BP by 100% (630 vs

300 kg/ha) and that of the local control by 500% (630 vs 110 kg/ha). Yield differences of RPL 1, RPL 2, and BP did not vary significantly in any environment.

Evaluation of IBPGR collection of Voltaique millet cultivars. Forty selfed progenies of local cultivars with little DM susceptibility (<10%) in 1982, were further screened for disease reaction and evaluated for agronomic performance in 1983. A mixture of the most susceptible six entries from 1982 was sown in every 10th row as an infector line. Results indicated that screening entries less susceptible to DM was fairly effective (Table 30). Of 40 samples screened in both years, 32 (80%) had infection index values of 10% or less, while the infection index for the susceptible control was 49% in 1982 and 31% in 1983.

The photoperiod-sensitive entries less susceptible to DM that combined drought tolerance and better agronomic characters and yield included CVP 480, CVP 162, and CVP 43. All these entries had good head size.

Breeding from crosses. Crossing selected genotypes is important in creating new variability so that a combination of desirable characters may be selected from two or more parents. We have crosses between local cultivar lines and promising introductions at various stages of evaluation. We need photoperiod-sensitive genotypes because of their adaptation in the target areas.

Crosses between photoperiod-sensitive and photoperiod low-sensitive parents yield a preponderance of photoperiod less-sensitive, early-maturing segregates. It is necessary to screen large populations and continue recurrent selection to increase the frequency of genes, which control late maturity and photoperiod sensitivity. Pronounced effects of micro-plot variation on flowering of millet plants, especially under drought stress, greatly confounds genetic differences in flowering. We postulate that early selection for photoperiod-sensitive genotypes should be more effective under non-drought conditions.

Experimental varieties derived from progenies of late flowering (1 to 15 September) F_1 selections flowered 21 to 31 August when seeded 12 June or 29 June. The material was therefore photoperiod sensitive but not enough for early sowing. Some experimental varieties seeded June 29 yielded more than 1 t/ha at Kamboinsé. Their potential for late sowing will be further explored. Plants with other desirable attributes that flowered after 10 September have been selected from F_4 plots where 50% of them flowered in September.

Table 30. Downy mildew infection index (%) of less susceptible and susceptible pearl millet cultivars, Upper Volta, 1982 and 83.

Cultivar reaction	1982	1983
Less susceptible[1]	8	6
Susceptible	49[2]	31

1. Mean of 40 cultivars.
2. Mean of six most susceptible cultivars mixture used in infector rows in 1983.

One cross (Kapelga × GT 79) showed strong correlation between late heading (photoperiod sensitivity) and hairy-leaf character. Other segregating populations showed a similar correlation, so we may use hairy-leaf character in screening seedlings to increase photoperiod-sensitive genotypes.

An early-maturing composite was derived by intercrossing selections from the most promising entries and ergot-resistant lines. Lines with good agronomic characters and resistance/tolerance to major diseases were identified and used as parents in crosses to breed full-season varieties

Striga Resistance

IDRC supports the ICRISAT Upper Volta program to identify cultivars of pearl millet resistant to *Striga* and to improve them for yield, food quality, etc. In 1979 we started screening West African local varieties and introductions from ICRISAT Center. So far emphasis is given to purifying the less-susceptible cultivars by continuous selfing and selecting in *Striga*-sick plots and in pot experiments.

Millet varieties highly resistant to *Striga* are yet to be identified. But promising selections are being screening in international nurseries in Niger, Senegal, Sudan, and Upper Volta. The 1983 field screening trials in Niger and Upper Volta showed no significant varietal different for *Striga* resistance. Individual plant selections made in pot experiments in Kamboinsé in the dry season 1983, however, gave encouraging results in pot tests in the rainy season 1983. Four selections, Ex-Bornu 6, Inbred 5258-1-19-1, P 2627-1-29-1, and Inbred 5258-1-19-4 were significantly less susceptible than the most susceptible selection.

Several progenies from crosses between less susceptible varieties have shown lower *Striga* incidence and better grain yield in sick plots in Upper Volta and Niger. The *Striga*-resistant population (formed by random mating less susceptible varieties) was tested in *Striga*-infected plots in Upper Volta and Niger. This population will be improved for *Striga* resistance, yield, and other desirable traits by recurrent selection. Several *Striga*-free plants will be selfed in each selection cycle and advanced by the pedigree method.

Senegal

Breeding

Our objectives are to improve grain yield and its stability, grain size, harvest index, resistance to diseases and pests, and productive tillering ability, and to determine the best cultural practices for newly developed varieties.

The millet experiments in 1983 were planted at four locations representing diverse millet-growing regions—Bambey, Darou, Louga, and Nioro. Rainfall was 250 to 300 mm below normal at each location. Bambey had a 50-day drought just after planting, and total rainfall at Louga, 146 mm, was lowest in 66 years (average 447 mm). The drought at Nioro was at flowering stage; at Darou, at seedling stage. Selections were therefore based on a combination of visual scores, disease incidence, morphological characters, and yield; 1983 provided an opportunity to select material under severe drought.

Plant Improvement

Improvement of synthetics. The first cycle S_1 recurrent selection in Souna III and IBV 8004, was completed in the 1982 off-season. Shibras were eliminated from Souna III and grain yield was improved by 7% in IBV 8004. The second cycle of recurrent selection in these synthetics was initiated during off-season 1982/83 by producing half-sibs in each. Using data from Bambey, Louga, Nioro, and the disease nursery, we selected 36 progenies from Souna III and 42 from IBV 8004 for recombination. The selected half-sib families are being recombined using S_1 seed from DM-free plants. After one more cycle, final comparisons will be made between the improved and originial synthetics.

Inbreds and synthetics. Three hundred and eight F_4 progenies derived from crosses among 48 selected entries were grown at three locations in single row plots. Eighteen were selected and are being used to form various synthetics based on height, maturity, and bristliness. Fifty-six diverse F_4 progenies will be advanced to develop inbreds. We gave 24 F_4 progenies exhibiting varied reactions to diseases in different locations to the pathologist at Institut Sénégalais de Recherche Agricole for studies on race differentiation.

Two hundred and forty F_2 populations from Senegalese × non-Senegalese crosses were grown at Bambey and Nioro during the 1983 rainy season. Plants from the selected 346 F_3 progenies which are being grown during the off-season will be selected to form synthetics.

Hybrids. Twenty-two of 117 hybrids from different male-sterile lines were selected for retesting in 1984, and 44 partial inbreds were selected to generate new hybrids on 3 male-sterile lines—111A, 81A, and 1055A. In a line × tester analysis, 2 male-steriles (111A and 81A) and 2 inbreds (IBMI 8108 and IBMI 8206) were the best general combiners for grain production.

Trials and Nurseries

National yield trials. During 1983, synthetic

Millets in Senegal: above, a farmer harvests his crop near Bambey; below, ICRISAT increases seed of a newly developed dwarf variety in efforts to improve it to match farmer expectations in the region.

IBV 8001 ranked highest in grain yield at two locations (Darou and Bambey) followed by H 7-66, IBV 8004, and Souna III in the advanced yield trial. Over four years and four locations IBV 8001 averaged 20% and IBV 8004, 18% more than Souna III, and both these entries maintained a greater level of DM resistance, had a higher seed weight, and matured slightly earlier than Souna III. Extension agencies multiplied foundation seed of these two synthetics on 100 ha in 1983.

A dwarf experimental variety 3/4HK-B78(I), although only 3% superior to Souna III in grain yield, was highly appreciated by farmers because it is short with long heads and many tillers. We hope to improve it for grain size and crop establishment through limited backcrossing.

Regional trials. Two synthetics IBMV 8301 and IBMV 8302 were contributed to ICRISAT zonal adaptation trial, and 25 F_5 bulks to the exchange nursery.

Several years of regional testing shows that the material bred in Niger performs well in Senegal while material bred in Sudan is the least adapted. In IMZAT-83, the highest yielding entry was IBMV 8302 (740 kg/ha) followed by ITMV 8002 and ITMV 8001. All entries except IEMP 1 and IEMP 2 and Nigerian composite were statistically equivalent to Souna III in grain production. We selected from the exchange nursery five entries from Senegal (F_4B_7, F_4B_5, F_4B_{20}, F_4B_{16}, and F_4B_{11}) and one from Sudan (ISMI 200) for use in our breeding program.

International nurseries. Five international nurseries from ICRISAT Center were planted at Bambey. Four pairs of male-steriles, nine disease-resistant lines, five inbred lines from source material inbred nursery, and six populations from the African Resource nursery were selected for replanting in the 1984 rainy season.

Two disease nurseries, IPMDMN and IPMSN, were conducted by the ISRA pathologist. Most of the material was resistant, but agronomically poor.

Development of Cultural Practices

Four varieties—Souna III, H7-66, IBV 8004, and 3/4HK-B78(I)—were planted at 23 plant densities from 3607 to 207 925 plants/ha) in a fan design at Bambey to try to determine the optimum plant population for each variety. Two years' data indicate that the optimum plant population for different varieties is from 10 000 to 30 000 plants/ha.

A trial consisting of those four varieties at two spacings (90 × 90 cm and 90 × 45 cm) with two plants per hill, and fertilizer at 0, 31:21:21, or 61:31:31 was planted at Bambey and Louga during the 1983 rainy season. Differences among varieties, fertilizer levels, and spacings were not significant for grain yield at either location. Wider spacing significantly increased plant height and ear length, and induced earliness at Bambey. The only significant interaction was fertilizer × spacing at Louga. Two years' results show that increased plant population neither significantly nor economically increases grain yield. So productive tillering, head length, and grain size should be the selection criteria to improve millet yields in Senegal.

Looking ahead. Two yield trials will continue in collaboration with the national program. Three entries—IBV 8001, IBV 8004, and 3/4 HK-B78(I)—will be demonstrated in farmers' fields in collaboration with extension agencies. Two synthetics, Souna III and IBV 8004 will be improved for another cycle by the half-sib method. We will use backcrossing to improve seed size of 3/4 HK-B78(I). More efforts will be made to improve the material for resistance to diseases, pests, and drought.

Mali

Breeding

Many F_3 selfs were selected in 1983 from segregating progeny of Malian × Malian and Malian × exotic African crosses. Experimental synthetics were then constituted during the 1983 off-season, using the selected F_3's.

Six bulk S_1 landrace varieties from the 6th Region (Goundam) were identified with potential *Raghuva* resistance and excellent plant expression at droughty locations.

S_1 progeny of the Douron landrace were 77% free from DM and 89% free of shibras. Since all the 50 lines contained shibras and DM-infected plants, it appears that it is easy to purge local varieties of DM susceptibility and shibras by selfing and selecting.

Village-level, paired-preference tests showed that millets with large (10g/1000 seed) round grains dehull easier than smaller-grained millets.

Finger Millet (*Eleusine coracana*).

We have found finger millet well adapted in Mali where rainfall exceeds 1000 mm. In a 1983 agronomy trial at the Tierouala station, each nitrogen unit from 1 to 20 units added 25 kg grain/ha. At 20N 15P, yields exceeded 2t/ha. On three farmers' fields, yields of 600 to 800 kg/ha were obtained without added fertilizer.

We found that the local staple food, prepared from a mixture of 75% *E. coracana* flour and 25% sorghum or millet flour proved highly acceptable to Malians.

Farmers are very interested in our efforts to introduce *E. coracana* as a new food crop to be used as a late-planted security crop at the end of rotation cycles.

Nigeria

Breeding

We continued to concentrate research efforts this year on developing improved millet cultivars with wide adaptability and high, stable grain yield. We also selected for short plant height, early maturity, increased productive tillering, and downy mildew resistance.

Although the short rainy season and below average rainfall reduced yields in late-maturing sorghum and crops planted later in the season, the early-maturing millet planted was not seriously affected.

Plant Improvement

A gene pool was initiated by intermating a total of 252 local germplasm, single-plant selections with a bulk mixture of 264 introduced pollen-parental selections. All these pollen-parental plants were selected in 1982, on the basis of agronomic desirability. The resulting progeny will form a gene pool from which parental lines will be derived for synthetic and experimental varieties.

During the 1983 season we used severe disease pressure in our sick plot to test improved lines from our programs in Nigeria, Senegal, Upper Volta, and ICRISAT Center.

Of the 252 base parental selections from our Nigeria program, 98 showed resistance to the major millet diseases, DM, smut, and ergot. And 111 of the 264 pollen-parental selections from the program showed resistance to these diseases.

Three selections from our Senegal program (ICMS 8142, IBV 810×3/4 HK-B78, and IBV 8108×IVS 5454), 1 from Upper Volta (KEV 81-5), and 34 from ICRISAT Center resisted the major diseases.

Trials and Nurseries

Much of the research effort this year was on the yield testing of newly developed, improved selections. We collaborated in IMZAT-83 and PMHT-83.

In yield trials at Samaru and Kano, 15 improved experimental varieties equalled or exceeded the improved local controls, Ex-Bornu and Nigerian Composite for the third year. The 15 are INMV 12, 46, 37, 20, 40, 4, 6, 42, 49, 10, 23, 2, 62, 76, and 47. Eight other improved experimental varieties have yielded, for a second year, similar to or better than the improved local controls. They are INMV 71, 119, 9, 39, 55, 36, 68, and 141. All 23 will be evaluated further in a joint yield trial with the national program.

We contributed 3 entries (INMV 8220, 8212, and 8210) to IMZAT-83. At our Kano, Nigeria, location two entries were the top grain yielders, INMV 10 at 3333 kg/ha and INMV 20 at 3232 kg/ha. The local improved control, Ex-Bornu, yielded 2805 kg/ha.

Over all trial locations in Africa, INMV 8220 was the highest yielder, indicating the good regional adaptability of this line. It was encouraging that improved selections from other ICRISAT programs in Niger, Senegal, and Upper Volta, also yielded well at Kano.

In PMHT-83, smut and DM were the major problems. Only 4 (ICMH 82506, ICMH 82601, INM 82128, and MBH 110) of the 16 entries showed low DM incidence, and smut disease was uniformly high among all 16.

Sudan

Breeding

The objectives of the program are to develop superior genotypes that produce higher and more stable grain yields than the existing local varieties, with acceptable agronomic and food quality characteristics for the millet growing regions of the Sudan. The research program is divided into six projects to achieve the objectives.

Plant Improvement

More than one hundred new variety crosses were evaluated. Two local varieties—Mansori from eastern Sudan and Bayuuda from southern Darfur—produced promising F_1's and a high degree of heterosis was observed in 18 new combinations. In the F_2 populations, 196 single plants from 35 populations and 233 single plants from 46 population were selected at Wad Medani and El Obeid, respectively. From a total of 495 segregating progenies (F_3 onwards) ten were found uniform, agronomically desirable, and high yielding; those have been selected for entry in the national trials. Four hundred and nine single plants were also retained from the segregating progenies nurseries grown at Wad Medani and El Obeid.

Male-sterile lines, ms 81A and ms Ex-Bornu, were tested for possible use in the Sudan breeding program. Ms 81A was found unsuitable under Sudanese conditions; but three experimental hybrids made on ms Ex-Bornu have shown promise. We have obtained new seed parents from the Center program to expand our program on development of seed parents and hybrids.

Among the populations submitted to national and international trials, IVP C_3 bulk (IEMV-1), ISMV 8223 (experimental variety derived from the inter variety population), and Bristled Population C_1 bulk have shown promise. Three local varieties of southern Darfur-Bayuuda, Wad El Lahaw and Kori are being improved by eliminating unproductive wild type plants (shibras); two cycles of selection have been completed. Five selections from local landrace collections—ACC 536-12, 600-3, 600-4, 603-6, and 645-4 were identified as useful and included in the working collection.

Nine entries in the downy mildew and smut resistance nursery were free from DM at Dimsu. Three genotypes from the *Striga* resistance trial—82 S 131, 82 S 125, and 82 S 129 were *Striga*-free at Nyala, Synthetic ICMS 7817 was also *Striga*-free at Kadugli.

Trials and Nurseries

In the National Pearl Millet Trial, six entries—ICMS 7817, KMDC, IVSH 78, ITV 8003, NMB 33, and Bristled Population C_1 bulk were found promising and have been selected for reevaluation in 1984. ICMS 7817 gave 39% more grain yield than the local variety Kordofani at El Obeid. Three entries, namely ISMI 171, ISMI 199, and ISMI 200 performed well in the initial yield evaluation trial 1. ISMS 8307, WCP 8004, MCP 8003, and IVC 80082 were selected from the initial yield evaluation trial 2 for retesting in the national trials. In the IMZAT-83 our intervariety population IEMV 1 ranked first at El Obeid with a grain yield of 1003 kg/ha (which was 57% higher than the local check) and ranked second at Nyertete with a yield of 197 kg/ha.

Two international trials and the uniform progeny nursery were grown. Nine genotypes were found superior to the checks in the Advance Population Varieties Trial and three top ranking entries—ICMV 82225, ICMV 82116, and ICMV 82111 were selected for further testing. ICMS 8139 was selected from the Pearl Millet Synthetic Trial to include in the national trials of 1984. Individual plant selections were made in 26 lines of the uniform progeny nursery and 61 plants were retained for use in the breeding program.

Workshops, Conferences, and Seminars

Second Workshop of the Eastern Africa Sorghum and Millet Improvement Network

One of the main objectives of the ICRISAT/SAFGRAD program in eastern Africa is strengthening the sorghum and millet research network in the region. To this end annual workshops for active research workers in the region were organized in 1982 and 1983. National programs of Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda, Yemen AR, and Yemen PDR are participating in the workshops and have agreed to take part in the regional research network. The second workshop held in Rwanda, was attended by 30 participants. Results of the 1982 crop season were discussed with emphasis on those of Rwanda, the host country. The proceedings are in press.

Pearl Millet Field Days

Pearl millet field days were held at ICRISAT Center, 13 September, at Haryana Agricultural University, Hissar, 20-22 September, and at Bhavanisagar, 28 September. Holding three field days in different locations allowed a large number of scientists (58) to participate, permitted each to select materials adapted to his own location, and helped focus discussion on common needs and problems.

Looking Ahead

Physical stresses. We will continue to investigate the contribution of selected physiological and morphological plant characters to yield under various environmental conditions and initiate studies to understand the developmental consequences of photoperiod in controlling flowering and the part it plays in adaptation.

We will complete the comparison of the line-source technique and empirical screening for midseason stress, and attempt (with a water-balance approach derived from long-term weather data) to classify millet-growing regions for probable patterns and intensities of stress.

Biotic stresses. Large-scale field screening for resistance to DM, ergot, and smut will continue at ICRISAT Center, and for rust at Bhavanisagar. The large-scale field screening technique for rust will be refined.

Multilocational testing for resistance to diseases will continue in India, and at as many locations as possible in Africa. Collaborative research will continue with the University of Reading on pathogenic variability in DM and with Imperial College, London, on mechanisms of resistance to ergot.

Efforts will be intensified to increase DM resistance in elite cultivars and breeding lines and to increase background diversity and agronomic eliteness of lines that resist ergot, smut, and DM. Identifying and developing resistance to more than one disease in agronomically-elite material will continue.

Microbiology. We will test the stability of millet cultivars' response to inoculation with N_2-fixing bacteria over seasons and locations. More bacterial cultures will be screened for nitrogenase activity to obtain strains for field-trial inoculations.

We will continue to use the ^{15}N isotope-dilution technique in a greenhouse to screen lines of millet for ability to stimulate nitrogen fixation. ^{15}N-enriched gas will be used to measure N_2-fixation rates of selected seedlings.

Effects of different levels of mineral nitrogen on nitrogenase stimulation by millet plants will be studied using C_2H_2 reduction assays.

We hope to initiate work on N_2-fixation at the ISC, to determine the extent of nitrogen fixation and to isolate and compare bacterial strains.

We will field test the efficiency of VAM isolates collected from Rajasthan for promoting growth and phosphorus uptake. A detailed survey of the crop grown in West African SAT regions for mycorrhizal status and for plant and soil P content will be carried out. We will seek further confirmation of genotype dependence of VAM colonization rates and responses by conducting trials outside ICRISAT Center. We will study VAM's contribution to increasing rock phosphate sources' efficiency when substituting for P fertilizers, and attempt to standardize a technique that differentiates the efficiencies of plant-VAM symbioses by phosphorous uptake and translocation.

Plant improvement. Mobilizing genetic variability from exotic African materials will continue with emphasis shifting from raw germplasm to breeding lines/promising varieties in West African breeding programs. Selection in three-way crosses and backcrosses with adapted materials will be attempted, with continued emphasis on breeding for DM resistance.

More emphasis will be given in the synthetic and hybrid parent projects to using high yielding progenies from the population-improvement and source-material projects.

Nuclear diversification of the A_1 system of male-sterility will continue with emphasis on shorter plants and medium maturity. We will explore the utility of other cytoplasmic systems of male-sterility and study the nature of cytoplasmic diversity.

We will continue to conduct IPMAT, participate in the AICMIP testing system, and run annual nurseries. Seed will be supplied worldwide and relations strengthened with SADCC countries and INTSORMIL millet researchers.

We will begin selecting for smut and DM resistance in the population improvement project. If required, we will introgress appropriate genotypes, particularly sources of resistance, to augment variability for yield (particularly seed size) and disease resistance. We will investigate further procedures for making experimental varieties, and selecting for seedling emergence in composites.

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Contents

Physical Stresses 121
- Drought Tolerance 121
- Germination from Limited Water in Seedbed 121
- Photoperiod 122

Biotic Stresses 123
- Diseases 123
  - Surveys 123
  - Fusarium Wilt (*Fusarium oxysporum* f.sp. *ciceri*) 123
  - Other Soilborne Diseases 125
  - Ascochyta Blight (*Ascochyta rabiei*) 125
  - Botrytis Gray Mold (*Botrytis cinerea*) 125
  - Stunt (Pea Leaf-Roll Virus) 126
  - Cooperative Disease Nurseries 126
- Insect Pests 126
  - Surveys 126
  - *Heliothis armigera* 126

Biological Nitrogen Fixation 129
- *Rhizobium* Distribution and Field Evaluation 129
- Screening *Rhizobium* Strains in Pots 129
- Method of *Rhizobium* Application 129

Grain and Food Quality 132
- Cooking Quality 132
- Nitrogen and Irrigation Effects 132
- Antinutritional Factors 132
- Anatomical Structure of Seed Coats 134

Plant Improvement 134
- Breeding Methodology 134
- Off-Season Nurseries 134
- Breeding Desi Types 135
- Breeding Kabuli Types 135
- Extending Adaptation of Chickpea 136
- Plant Type 137

Cooperative Activities 138
- International Trials and Nurseries 138
- Distribution of Breeders' Material 139
- Cooperation with AICPIP 139
- Cooperation with ICARDA 139
  - Plant Improvement 139
  - Diseases 145

Workshops, Conferences, and Seminars 148

Looking Ahead 149

Publications 149

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CHICKPEA

Our principal objective continues to be the development of improved cultivars and genetic stocks of desi- and kabuli-type chickpeas capable of increased, stable yields in traditional and nontraditional cropping situations.

In 1982/83, most of our work proceeded as follows: at ICRISAT Center, (18°N, 78°E) aimed at early-maturing desi types; at Hissar (29°N, 75°E), in cooperation with Haryana Agricultural University (HAU), for late-maturing desi and kabuli cultivars; and at Aleppo (36°N, 37°E), Syria, at our sister institute ICARDA, on kabuli types for winter or spring sowing in the Mediterranean basin and in South and Central America.

Subsidiary centers included: Gwalior (26°N, 78°E) in central India for testing, and Wadoora (34°N, 75°E) in Kashmir, northern India, and Sarghaya (36°N, 36°E), Syria, for off-season multiplication. We acknowledge the contributions of many cooperators who made it possible to increase the number of international trials and nurseries distributed during 1983.

In India, the season was favorable for chickpeas. At ICRISAT Center rainfall in 1982, though slightly below average, extended into early November. That facilitated land preparation and sowing at optimum times for crop emergence and establishment, which were excellent. Lower than average minimum temperatures in December and January helped extended crop growth so seed yields of several entries in rainfed trials exceeded 3 t/ha. Disease problems were slight. *Heliothis* infestations, about average, caused moderate damage.

At Hissar, rainfall during the growing season was less than normal, so ascochyta blight and botrytis gray mold did not appear in epiphytotic form. But severe salinity problems caused high plant mortality and extremely variable results. *Heliothis* populations were normal with localized heavy damage at the podding stage.

In Syria, winter temperatures again were low, below zero more than 50 nights, which adversely affected crop growth. Spring rainfall was so low that ascochyta blight in commercial crops was less severe than in the previous season, and 1983 yields were good. In the Mediterranean basin, leaf miner *Liriomyza cicerina* was widespread and *Heliothis* infestations were sporadic.

Physical Stresses

Drought Tolerance

In India chickpeas are grown between 11 and 30°N mainly as a nonirrigated, postrainy-season crop. The temperatures and evaporative demands of the atmosphere are high and growing seasons short (around 90 days) in peninsular India and the crop is subjected to progressively increasing soil and atmospheric stress with advancing age. In such environments early-maturing genotypes are better adapted because they escape drought.

The drought tolerances of 49 early-maturing genotypes that were tolerant or susceptible to drought in 1981/82 were evaluated in replicated field experiments on a deep Alfisol and a Vertisol at ICRISAT Center. The technique used was described in ICRISAT Annual Report 1982, pp.110-111. ICC 10448, the most tolerant genotype, matured about 80 days after sowing, and produced 2050 kg/ha seed on the nonirrigated Vertisol and 800 kg/ha in the drought environment on the Alfisol (compared with 200 to 400 kg/ha for the susceptible entries).

Germination from Limited Water in Seedbed

In India, chickpeas are sown in October and November when monsoon rains have ceased and

[redacted]

temperatures are low. Fields are generally fallowed in the rainy season, and moisture is conserved in the soil profile by such cultural practices as repeated harrowing to control weeds and improve infiltration of rainwater and planking to reduce evaporative losses. After rains cease and before temperatures drop, soil moisture in the top 10 cm starts receding and may become insufficient to support germination and emergence; so stands are often poor. In a laboratory method developed at ICRISAT, soil of standardized water content is used to detect genotypic differences in seed germination and emergence from limited soil moisture in germination trays (ICRISAT Annual Report 1979 1980, pp. 81-82). More than 1000 germplasm lines have been thus screened.

To relate laboratory results to field performance, we tested a few genotypes in a field experiment. Eighty seeds were sown 5 cm deep on each of three dates with a JD-7100 planter, in rows 75 cm apart (Fig 1). Emerged seedlings were counted 12 days after each sowing. Soil moisture in the surface layer decreased as did number of emerged seedlings with progressive delay in sowing (Table 1). Distinct genotypic differences in ability to germinate and emerge were recorded (Table 2).

Table 1. Percentages of seedlings emerged and soil moisture contents (0-10 cm soil depth) 12 days after sowing from 3 sowing dates (average of 6 chickpea cultivars, plot size for each cv 2 rows 4-m long, 80 seeds/plot). ICRISAT Center, 1982/83.

Sowings	Days after 1st sowing	Seedlings emerged (%)	Soil moisture content (%)
1st	-	85 (68)[1]	26
2nd	7	80 (64)	23
3rd	16	58 (50)	20
SE	-	±(3.0)	±0.3

[1] Angular transformed values.

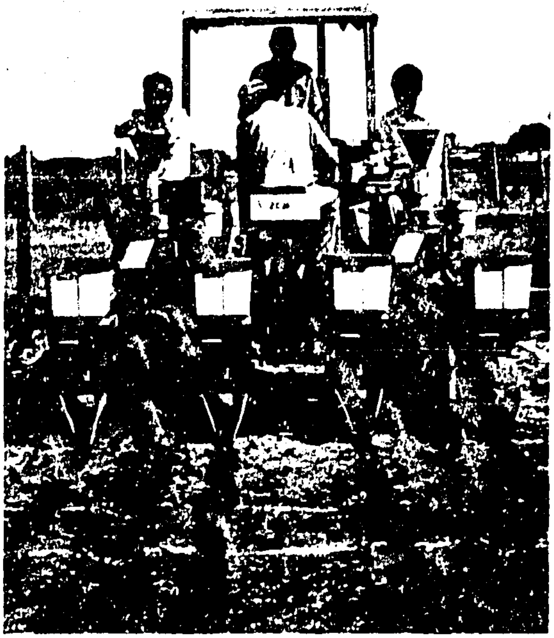


Figure 1. Mechanized planting at a uniform depth of 5 cm with a cone planter on a Vertisol, ICRISAT Center, 1983.

Photoperiod

Chickpea breeders at ICRISAT Center routinely use a rapid generation-turnover technique with long-day treatments. Three crops a year are now harvested, which was not previously possi-

Table 2. Seedlings emerged in 3rd sowing expressed as % of seedlings in 1st sowing (plot size, 2 rows 4-m long, 80 seeds/plot), for indicated chickpea lines, ICRISAT Center, 1982/83.

Cultivar	% seedlings emerged
K 850	66.4 (56.0)[1]
G 130	81.8 (64.3)
Annigeri	88.4 (70.5)
Rabat	90.0 (79.4)
K 4-1	52.2 (47.2)
L 550	38.5 (37.7)
SE	±(8.02)

[1] Angular transformed values.

ble. Field experiments conducted to simplify the technique indicated that chickpeas have no juvenile phase. Sensitivity to photoperiod was more or less equal at different stages between 7 and 20 days after sowing. Earliest maturation (75 days) was achieved with 20 long-day treatments immediately after sowing. Fluorescent and incandescent light sources induced flowering and hastened maturity equally. But growth and yield were reduced more by fluorescent lights. Long-day treatments always reduced yield considerably. Pronounced morphogenic effects on leaf expansion, internode elongation, and branching were observed again (see ICRISAT Annual Report 1982, pp. 113-115).

Biotic Stresses

Diseases

Surveys

We conducted surveys in Australia, USA, and parts of India. In the USA, botrytis gray mold (*Botrytis cinerea*), stunt (pea leaf-roll virus), and mosaics (pea enation mosaic and pea streak viruses) were common in chickpea trials at experimental stations in Washington and Idaho states. The first two diseases were observed for the first time in the USA. In Arizona state, stunt and collar rot (*Sclerotium rolfsii*) were observed.

In Australia, phytophthora root rot (*Phytophthora megasperma* f.sp. *medicaginis*) was the most important disease, followed by iron chlorosis. In central India, wilt (*Fusarium oxysporum* f.sp. *ciceri*), (Fig.2), collar rot, and dry root rot (*Rhizoctonia bataticola*) were the three most important diseases; stunt was of minor importance. Collar rot was the most important disease in parts of Madhya Pradesh and Orissa, where chickpea is broadcast in standing rice crops before harvest.

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

Screening for resistance. The numbers of genotypes screened for wilt resistance in wilt-sick plots and their wilt incidence in 1981/82 and 1982/83 are shown in Table 3.

Breeding for resistance. Eight crosses were made between wilt-resistant and north Indian kabuli cultivars. Further backcrossing was done to transfer wilt resistance to ILC 482 and 484. Crosses of desi materials were not attempted because desi populations with sufficient wilt resistance are available.

Table 3. Results of screening chickpea genotypes for wilt resistance in wilt-sick plots over two/three years at ICRISAT Center.

Category	Year screening began	No. screened	No. showing wilt incidence, 1981/82		No. showing wilt incidence, 1982/83	
			10-20%	<10%	10-20%	<10%
Germplasm	1982/83	261	NS	NS	14	0
Germplasm	1981/82	71	71	0	15	20
Germplasm	1980/81	25	0	25	5	20
Large-seeded	1982/83	372	NS	NS	9	0
Double-podded	1982/83	88	NS	NS	0	0
Kabuli	1981/82	8	0	0	3	0
Heliothis-resistant	1982/83	57	NS	NS	6	0
Heliothis-resistant	1981/82	9	9	0	4	0
Ascochyta-tolerant	1981/82	9	NS	NS	1	0

NS = Not screened.

Figure 2. In studying diseases, ICRISAT scientists survey farmers' fields to assess damage and collect plant specimens to detect races of pathogens and their distribution. Here, wilt damage in a field in Orissa is shown.

At ICRISAT Center, 97 F_2 populations and 677 F_3 progenies were screened in a wilt-sick plot and 3000 single plants and 400 progenies were selected. More than 1200 F_4 and more advanced generation lines were evaluated; 500 were selected for further tests, and 175 lines were compared in replicated trials.

At Hissar, 63 F_2s and about 600 F_3 and more advanced progenies were screened in wilt-sick plots. The F_2s were bulk harvested because of excessive vegetative growth, but 200 single plants and lines were selected among other generations; 157 more advanced lines were included in replicated trials.

From the trials, 30 entries will be contributed to the International Chickpea Screening Nurseries (ICSNs) and 27 to the International Chickpea Root Rot and Wilt Nursery (ICRRWN).

Inheritance studies. The cultivar K 850 carries a recessive gene, independent of that of C 104, conferring a late-wilting reaction to race 1 of *F. oxysporum* f.sp. *ciceri*. A third independent gene for late-wilting in H 208 apparently is dominant for early-wilting. The genetic constitutions of four resistant, one early-wilting, and three late-wilting cultivars in respect to the three genes have been established. The studies are crucial to the development of effective breeding strategy and they provide valuable basic information concerning host-parasite relationships.

Biology and epidemiology. Continuing studies indicated that *F. oxysporum* f.sp. *ciceri* survived 60 months in soil in which stubble from wilted plants was buried in March 1978. The experiment is continuing. In another study, depth at which infected roots were buried had no influence on survival of host tissue or fungus.

Influence of crop rotation and intercropping. A 3-year study on the influence of crop rotation and intercropping on wilt incidence in a wilt-sick plot showed no treatment effects on wilt incidence in the susceptible (nearly 100% mortality) cultivar, JG 62. We terminated the experiment.

Other Soilborne Diseases

Dry root rot (*Rhizoctonia bataticola*). Using the blotting paper technique developed at ICRISAT, we tested 297 lines that included selections from the multiple disease-sick plot, wilt-resistant lines, and kabuli lines developed by breeders at ICRISAT for resistance to dry root rot and identified 16 lines with resistance (3 rating on 1-9 scale; 1 = no disease, 9 = dead). F_2s of two crosses to transfer resistance to Annigeri were screened, and 149 single plants were selected for further tests.

Screening for multiple soilborne diseases. Germplasm accessions and lines were screened at ICRISAT Center in a plot with multiple diseases. These were, in order of prevalence: *F. oxysporum* f.sp. *ciceri*, *Rhizoctonia bataticola*, *Sclerotium rolfsii*, *F. solani*, and *R. solani*.

For the third time, we tested 195 accessions that had shown less than 20% mortality from wilt and root rots in the multiple disease-sick plot in 1979/80, and 50 of them showed less than 10% mortality this year. Of 46 germplasm accessions with less than 10% mortality in 1981/82, 38 maintained resistance in 1982/83. Nineteen of the 28 accessions that had promising resistance to wilt showed multiple resistance. We also found 6 of 40 kabuli chickpea lines developed by ICRISAT to be resistant to root pathogens when tested for multiple resistance.

Ascochyta Blight (*Ascochyta rabiei*)

Screening for resistance to ascochyta blight was carried out in isolation plant propagators in a greenhouse at ICRISAT Center. Of 91 germplasm accessions less affected by the blight in northern India in 1981/82, 8 (ICC 12, 478, 652, 801, 1416, 1468, 1472, 4033) showed moderate resistance (5 rating on a 1 to 9 scale) in 1982/83. Only one (No. 235-38) of the 15 lines from Haryana Agricultural University (HAU) showed moderate resistance. All the 18 *Heliothis*-resistant and two ascochyta blight resistant lines screened from ICARDA (ILC 202, 3279) were susceptible. We also tested 48 germplasm accessions that were resistant and moderately resistant to ascochyta blight in Pantnagar, and identified 1 (ICC 1069) with moderate resistance.

F_2 populations of crosses made in 1981/82 between ILC 72, 202, and 3279 (which have shown resistance in ICARDA fields), and north Indian desi and kabuli cultivars were screened by ICARDA (28 populations) in Pakistan, and by Punjab Agricultural University (PAU) and Himachal Pradesh Agricultural University in northern India (22 populations). Resistant plants were selected at all locations and were advanced as F_3 progenies. F_4 and F_5 generations of crosses made in 1980/81 were advanced by PAU.

Botrytis Gray Mold (*Botrytis cinerea*)

We continued screening germplasm accessions in isolation plant propagators by the procedure standardized last year. Of 48 germplasm accessions showing promise against botrytis gray mold in field screening at Pantnagar in 1981/82, only 4 (ICC 795, 880, 922, 1400) showed moderate resistance (5 rating on a 1 to 9 scale). Only 1 (ICCL 80004) of the 48 kabuli lines and 3 of the 62 desi lines developed by ICRISAT chickpea breeders showed moderate resistance.

We made 30 crosses between newly identified botrytis-resistant lines and adapted cultivars. Sixty F_2 and 49 F_3 populations were screened at Pantnagar in northern India, in collaboration with Govind Ballabh Pant University of Agriculture and Technology. In the absence of disease pressure, all were harvested as bulks for further testing.

Stunt (Pea Leaf-Roll Virus)

Field screening for resistance to stunt was continued at Hissar, where stunt incidence in the susceptible rows in the nursery averaged 80%.

Some accessions with less than 10% infection in the last 2 to 6 seasons showed similarly good reactions during 1982/83. All 11 accessions with moderate resistance to ascochyta blight and botrytis gray mold were highly susceptible to stunt.

Sixteen F_2 populations and 400 F_3 and more advanced progenies from crosses between stunt-resistant and adapted parents were screened in the stunt nursery at Hissar. Sixty progenies were bulked and 350 single plants selected for further evaluation; 23 of the best progenies will be assessed for yield in replicated trials at Hissar.

Five crosses were made to combine ascochyta blight and stunt resistance. The F_1s of four-way crosses made in 1982 to combine resistance to wilt and root rots, to wilt and ascochyta blight, and to ascochyta blight and stunt were advanced.

Cooperative Disease Nurseries

International Chickpea Root Rots/Wilt Nursery (ICRRWN). The 60 entries in the 1981/82 ICRRWN were sent to 25 locations in 18 countries; data were returned from 9 locations in 9 countries. Results were reported in Pulse Pathology Progress Report No. 24 (copies of this and other program-level publications obtainable from Pulses Improvement Program, ICRISAT). Three entries (ICC 6815, 8933, and ICCL 81005) had low incidence of the diseases at 7 locations.

Cooperation with AICPIP. We screened germplasm accessions, entries from All India Coordinated Pulses Improvement Project (AICPIP) Chickpea Varietal Trials, and breeding materials from AICPIP scientists for resistance to fusarium wilt and other soilborne diseases, ascochyta blight, and botrytis gray mold, and communicated the results to AICPIP scientists.

The second ICRISAT-ICAR Uniform Chickpea Wilt/Root Rots Nursery (IIUCWRRN) with 84 entries (48 from ICRISAT Center; 10 from Kanpur; 22 from Hissar; and 4 from Ludhiana) was sown at ICRISAT Center. The results are reported in Pulse Pathology Progress Report No. 25.

Insect Pests

Surveys

As in previous years, *Heliothis armigera* was the major insect pest of chickpea in almost all areas visited in India, but the damage varied widely. *Heliothis* was also heavily damaging in many areas of Pakistan. In northern India, *Autographa nigrisigna* and a few other pod-boring lepidoptera were important in local pockets and cutworms and termites reduced plant stands in some farmers' fields. In Syria and Jordan, the leaf miner, *Liriomyza cicerina* was common and damaging in most of the farmers' fields visited. *Heliothis* spp damage varied widely, but was major in southern Syria and northern Jordan.

Heliothis armigera

Host plant resistance. Field trials again showed spectacular differences in damage by *Heliothis* attacks between our resistant and susceptible selections (Fig. 3). Resistant selections have aroused a great deal of interest and we have supplied such seed to colleagues in national programs.

We have finished screening the available germplasm and are using the best selections in breeders' crossing programs. Unfortunately, most of our *Heliothis*-resistant selections are highly susceptible to fusarium wilt. Crosses are being made from which we hope to select progenies that combine disease resistance and increased resistance to the insect.

Although it is relatively easy to detect differences in resistance/susceptibility to *Heliothis* between plots of genotypes, single plant selection for resistance from segregating populations is not so easy. That was well illustrated in a trial comparing ICC 506 (resistant) and Annigeri

Figure 3. The control cultivar Annigeri (left) was severely damaged by *Heliothis armigera*. Resistant selection ICC 506 (right) has little pest damage and bears a good crop.

(susceptible) plants in separate plots (19 m^2), in alternate rows and as alternate plants within rows. Data from the trial are illustrated in Figure 4. Differences between the selections, measured by pod damage, were substantially reduced when the resistant and susceptible plants were alternated within rows. We know that some of the resistance results from nonpreference for oviposition but larvae migrate from plant to plant, thus masking differences between plants regarding attraction for egg laying. That difference, combined with the large variability commonly encountered in open field screening, prevents high success in single plant selection for resistance. We are researching methods to overcome that problem. Biochemists at ICRISAT and cooperators at the Max-Planck Institute, Federal Republic of Germany, are attempting to identify chemical differences between resistant and susceptible plants.

Breeding for resistance. *Heliothis*-resistance breeding continued to expand. We made 43 crosses involving newly confirmed sources of resistance in early-maturing desi and kabuli types. They included 3 diallel series (to study the inheritance of resistance and to recombine different resistance sources) and 8 crosses to transfer wilt resistance to *Heliothis*-resistant lines.

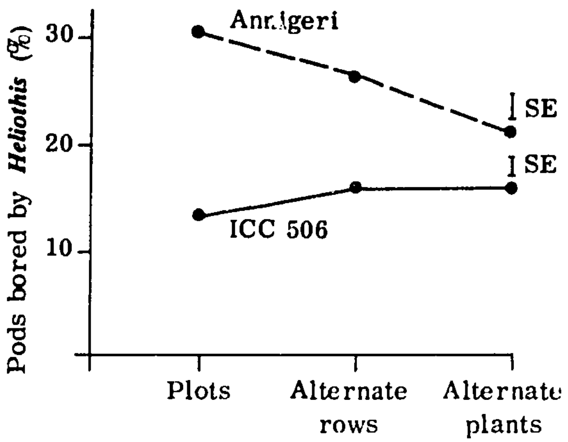


Figure 4. Pod damage caused by *Heliothis armigera* on chickpeas ICC 506 (resistant) and Annigeri (susceptible), grown on a Vertisol without pesticide protection in separate plots, in alternate rows, and as alternate plants in the same rows, ICRISAT Center, 1982/83.

Two F_1 6 × 6 diallel trials of early- and medium-maturing desi types at ICRISAT Center confirmed that additive gene effects account for most of the variation in *Heliothis*-damage percentages. But in the medium-maturity trial, nonadditive effects were evident so they may be important in some combinations.

We screened 110 F_2 populations and 738 early-to-medium maturing F_3 to F_5 progenies of crosses made in 1980/81 and 1981/82 at ICRISAT Center and 736 late-maturing progenies for the first time at Hissar, in unsprayed conditions. At ICRISAT Center, we selected 824 single plants and 33 rows; at Hissar, 826 single plants, for further tests. Since most of the *Heliothis*-resistant lines are extremely susceptible to *F. oxysporum* f.sp. *ciceri*, F_4 and F_5 progenies were also screened in a wilt-sick plot at ICRISAT Center. Most of them suffered complete, rapid mortality, but 20 progenies and 93 single plants that survived will be advanced for further tests.

Breeders' materials (selected in protected conditions) and *Heliothis*-resistant lines were again compared at ICRISAT Center (early and medium maturing) and at Hissar (late maturing). At ICRISAT Center, *Heliothis* damage was light, even in unprotected plots. Insecticide protection did not significantly affect seed yields, and interactions between entries and insecticide protection were not significant. At Hissar, *Heliothis* damage was more severe in the unprotected (20.7%) than in the protected (8.0%) trial and seed yields were significantly less in the unprotected trial, but differences among entries and the interaction between entries and insecticide protection were not significant. Although insect damage has varied widely, three years of tests have not demonstrated that breeders' lines either produce smaller yields than *Heliothis*-resistant lines in unprotected conditions or respond more to insecticide application.

Attractants for *Heliothis*. As described in the pigeonpea section of this report, we are monitoring catches of male moths in pheromone traps in a network covering the Indian subcontinent. At ICRISAT Center and at Hissar, we operate the traps in chickpea fields to monitor infestations. We are also searching for chemicals that will attract female *Heliothis* moths before they oviposit. Of a range of chemicals supplied by Beltsville Agricultural Research Center, USA, phenylacetaldehyde was the most promising. It attracted both male and female *Heliothis* moths into our standard traps. One trap, operated in a chickpea field at Hissar, in which 0.05 ml of phenylacetaldehyde was added to the rubber dispenser each week, caught a total of 147 males and 95 females in 12 weeks. A similarly baited trap, to which 0.01 mg of ascorbic acid was also added as an antioxidant, caught 177 males and 119 females. Such catches encourage us to continue this investigation, but they must be viewed in relation to catches from nearby pheromone traps that averaged 3430 male moths per trap over the same period.

Insecticide use. A trial in which we tested the use of endosulfan to protect early-, medium-, and late-maturing cultivars through the vegetative and reproductive stages gave an average increase in yield of 27% (protected: 1970 ± 33 kg/ha; unprotected: 1550 ± 33 kg/ha). Even though damage caused by *Heliothis* was severe during the vegetative stage, most of the increase was produced by protection during the reproductive phase.

Natural control. We recorded the incidence of parasites in the *Heliothis* populations in our chickpea fields. The two commonest parasites were *Campoletis chlorideae* and *Carcelia illota*. Parasitism rates rarely averaged more than 10% in the larvae collected.

Earlier observations indicated that some insectivorous birds may play important roles in reducing *Heliothis* larvae. We conducted a trial this year intended to quantify the role of birds. Plots were protected by nets that prevented birds from access to the *Heliothis* larvae on the plants. We recorded 27% more larvae of all instars, and 45% more of larger larvae, on the protected plots than on unprotected plots in November, and the protected plots tended to have more damaged pods.

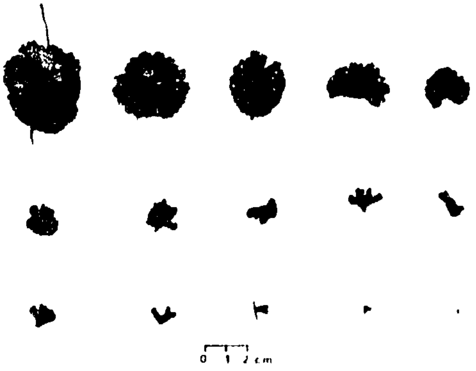
Biological Nitrogen Fixation

Rhizobium Distribution and Field Evaluation

We supplied *Rhizobium* strains and inoculants in response to 16 requests from 7 countries; 16 strains were sent to each of 16 research stations for AICPIP collaborative trials. As a result of such trials conducted at 12 to 16 locations for 2 to 3 years, one of our strains (IC 76) was recommended by the national program for use as an inoculant in India. Performance of the strain at 9 of those locations is shown in Figure 5.

Screening *Rhizobium* Strains in Pots

Following the demonstration that plant growth, nodulation, and N_2-fixation declined as soil temperature rose (ICRISAT Annual Report 1982, pp.117-118), we studied the performance of 20 *Rhizobium* strains at two soil temperatures. Seven liter pots, each containing 5 kg dry black soil, were sown with cultivar K 850 and inoculated with different *Rhizobium* strains in 4 replications. From 6 days after sowing, when the seedlings emerged, the pots were immersed in water baths at 25 and 32°C for about 8 hours each day, which provided mean soil temperatures in the pots of 23.9°C and 30.4°C, respectively, over the 46-day treatment period. The higher temperature substantially reduced plant growth and there were significant *Rhizobium* strain differences (Figures 6 and 7). The interaction between temperatures and *Rhizobium* strains was not significant. Strain CM 127 produced 20% more shoots than the noninoculated control at 25°C and strain CM 120 produced twice as many shoots as the noninoculated control at 32°C. Such strains are proposed for field evaluation in early-sown trials under high soil temperatures (ICRISAT Annual Report 1977-78, pp.172-173).



Variation in sizes of chickpea nodules noticed in farmers' fields in Rajasthan, India. ICRISAT microbiologists try to identify and promote lines that better exploit atmospheric nitrogen and boost yields.

Method of *Rhizobium* Application

Experiments at ICRISAT Center on Alfisols with fewer than 10 native chickpea rhizobia per gram of dry soil indicated that rhizobia applied on the seed coat (the traditional method) remained around the seed and did not move into the root zone while the soil remained dry (ICRISAT Annual Report 1982, pp.117-118). To further investigate, we conducted experiments on three soil types, each with fewer than 10 native chickpea rhizobia per gram of dry soil. Significant improvements in nodulation were observed in all three when the inoculant was applied in a water suspension (Table 4). When the inoculant was applied on the seeds, nodulation improvement was not consistent. The increase was large in sandy soils at Bawal, but

Figure 5. Responses to inoculation by *Rhizobium* strain IC 76 in chickpea at 9 locations. In parentheses are percent mean increases in grain yield achieved over 2 or 3 years of testing, 1980/81 to 1982/83. Site at Jabalpur shifted to Sehore in 1982/83.

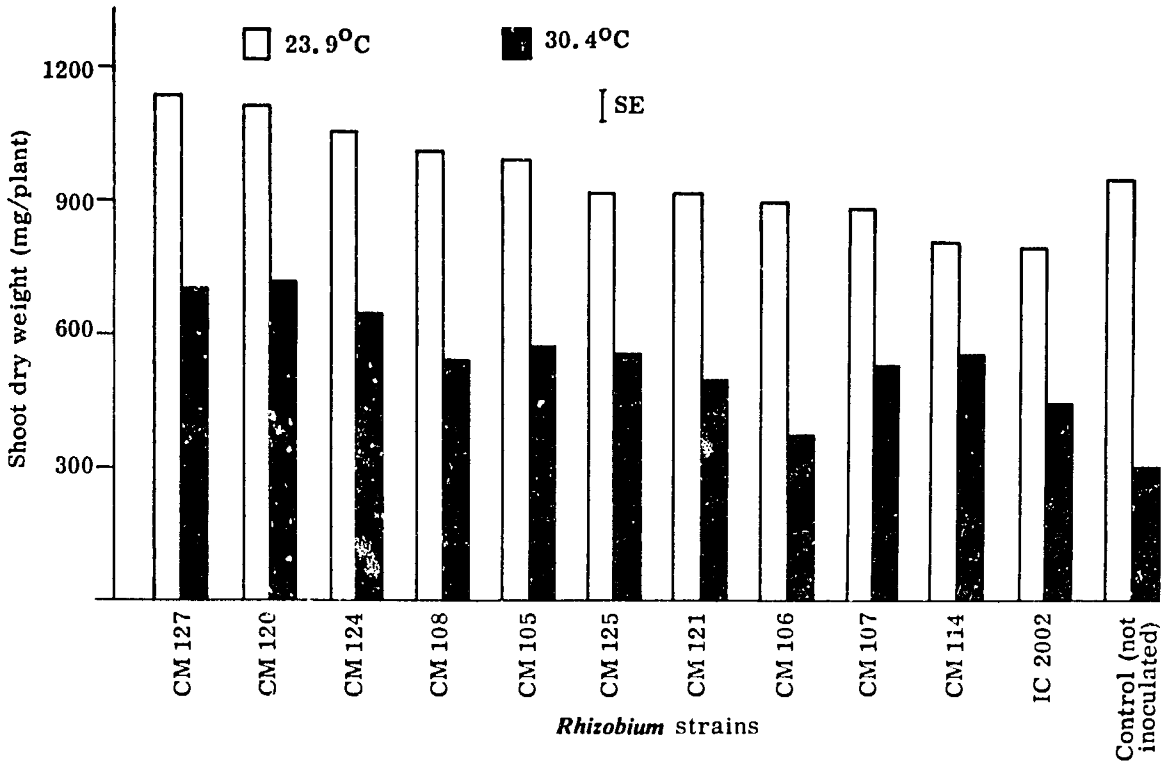


Figure 6. Growth of K 850 with indicated *Rhizobium* strains at two soil temperature regimes (mean of hourly temperatures for 46-day growth period).

small or nonexistent in the Vertisol at ICRISAT. Soil differences may partly explain the inconsistent responses to *Rhizobium* inoculation.

Unfortunately, the liquid suspension method of applying inoculant is difficult to practice in farmers' fields where chickpeas normally are grown with negligible inputs and receding residual soil moisture. A suitable method needs to be devised.

Table 4. Effects (nodules/plant) of indicated methods of applying *Rhizobium* to chickpea seed used in different soils with fewer than 10 rhizobia/g soil in the top 15-cm profile.

	Nodule numbers/plant		
Treatment	Sandy soil, Bawal, Haryana	Alfisol, ICRISAT Center	Vertisol, ICRISAT Center
Noninoculated[1]	2±0.1	1±0.2	6±0.9
Inoculant applied on seed coat	19±0.8	6±0.7	7±1.1
Inoculant suspended in water and applied at sowing	33±3.7	16±0.7	20±1.8

[1] The means of all noninoculated treatments, including those in which the same quantity of water was used as in the water-suspended inoculant treatment.

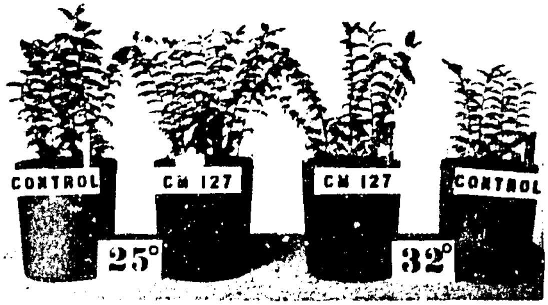


Figure 7. Potted chickpea plants serially from left, noninoculated control at 25 °C, inoculated with CM 127 at 25 °C, inoculated with strain CM 127 at 32 °C, and noninoculated control at 32 °C.

Grain and Food Quality

Cooking Quality

We initiated studies to determine the effect of geographic origin of seed on the cooking quality of chickpea. Dhal samples of five cultivars (Annigeri, BDN 9-3, Phule G 4, G 5, and G 7) each from four replicates grown both at ICRISAT Center and Rahuri (Maharashtra) were analyzed for cooking time and various physicochemical factors. Cooking times varied significantly among the cultivars, but not between locations. Phule G 7 required the longest cooking time (39 minutes) and BDN 9-3, the shortest (30 minutes). Texture value measured by the Instron food testing machine was highest for Phule G 7. We plan to analyze other cultivars from more locations to confirm these results.

Cooking qualities of whole seed and dhal samples of seven kabuli and six desi cultivars were determined (Table 5). The samples were from cultivars grown in unreplicated plots at Hissar. Differences between the desi and kabuli groups in cooking time, water absorption, solids dispersed, and texture were absent, confirming last year's observations.

Nitrogen and Irrigation Effects

A previous trial at ICRISAT showed that phosphate and nitrogen applied deep into the soil followed by irrigation increased seed protein. In a field trial in Vertisols with two cultivars and four levels of nitrogen with and without irrigation, nitrogen applications increased seed protein significantly (from 14.4% in the control to 16.3% with 80 kg N/ha). Seed protein of K 850 increased significantly with irrigation, but that of Annigeri did not (Figure 8).

Antinutritional factors

The role of polyphenols in inhibiting trypsin, chymotrypsin, and amylase in chickpea seeds was examined by *in-vitro* methods (Table 6). Polyphenols were extracted from whole seed samples by refluxing with acidified methanol, acetone, and methanol solvents. The polyphenols inhibited trypsin more than chymotrypsin and more in human salivary amylase than in hog

Table 5. Means and standard deviations of indicated cooking quality characteristics of desi and kabuli chickpea cultivars.[1]

	Desi (n=6)		Kabuli (n=7)	
	Whole seed	Dhal	Whole seed	Dhal
Cooking time (min)	67.0 ±2.8	45.3 ±3.9	66.4 ±6.9	46.8 ±3.4
Water absorption (g/g)	1.01 ±0.04	1.02 ±0.04	0.92 ±0.08	0.93 ±0.05
Solids dispersed (%)	15.9 ±2.9	23.2 ±1.3	16.4 ±0.7	21.7 ±1.7
Texture force (kg)	Not tested	289 ±54.0	Not tested	390 ±42.8

1. Samples boiled 45 min

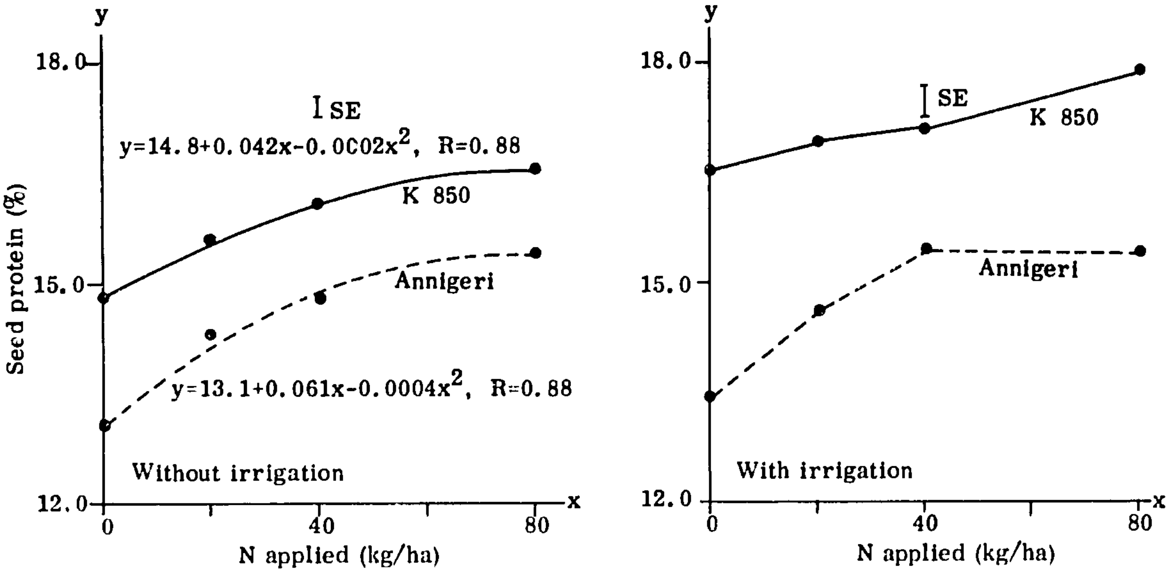


Figure 8. Seed protein content of two chickpea cultivars, with and without irrigation at four nitrogen (urea) rates. A quadratic relationship was calculated between seed protein and increasing nitrogen, without irrigation (left). With irrigation (right), such a relationship was poor.

pancreatic amylase. Adding polyvinylpyrrolidone (PVP) greatly reduced the enzyme inhibitory property of the polyphenols. Further, the polyphenolic compounds of the desi cultivars (dark testa) showed greater enzyme inhibitory activity than those of the kabulis (light-colored testa).

Tannin contents in the total polyphenolic compounds in chickpea seeds were determined by analyzing 67 germplasm accessions differing in seed coat color. Tannin contents were determined by the vanillin-HCl standard method and total polyphenolic compounds were estimated by the Folin-Denis method. Tannin contents of the cultivars varied from 0.07 to 0.23 mg/g; total polyphenols contents, from 2.36 to 6.15 mg/g (Table 7). Polyphenol concentration tended to be higher in dark- than in light-colored seeds, but tannin contents were not associated with seed coat color. Also, concentrations of tannins and total polyphenolic compounds showed no correlation.

Table 6. Differences among chickpea cultivars in the enzyme-inhibitory property of polyphenols.

			Enzyme inhibition (%)[1]			
Cultivar	Testa color	Polyphenols (mg/g sample)	Trypsin	Chymo-trypsin	Human saliva amylase	Hog pancreas amylase
Rabat	Light	1.9	33.6	26.3	29.8	17.5
L 550	Light	2.3	34.5	25.7	31.5	20.8
Pant G 114	Dark	5.3	86.4	72.5	73.4	56.9
G 130	Dark	5.8	88.7	79.0	80.3	64.5
USA 613	Dark	6.1	81.6	70.9	78.6	61.0
SE		±0.10	±1.83	±1.60	±1.74	±1.52

1. Based on assays of 200 μg polyphenols for trypsin and chymotrypsin and 250 μg polyphenols for amylase inhibitions.

Table 7. Tannin and total polyphenolic concentration (mg/g) in chickpea seeds of indicated testa colors.

Testa color	Number of cultivars	Tannins[1]	Polyphenolic compounds (Mean)
Off-white	10	0.23 ±0.08	2.36 ±0.12
Very light brown	7	0.23 ±0.07	2.66 ±0.20
Light brown	14	0.08 ±0.02	4.67 ±0.30
Brown	11	0.09 ±0.01	4.43 ±0.29
Dark brown	11	0.07 ±0.01	5.15 ±0.28
Black	13	0.10 ±0.01	6.15 ±0.30
Green	1	0.07	5.69

1. Expressed as catechin equivalent.

Figure 9. Cross sections (× 115) of mature seed coats of kabuli (above) and desi (below) chickpea cultivars.

Anatomical Structure of Seed Coats

The anatomical structures of seed coats of desi and kabuli chickpea cultivars were studied at different stages of seed development. Developing seeds of H 208 (desi) and No. 501 (kabuli) cultivars, grown on a Vertisol at ICRISAT Center in 1982/83, were collected 20, 35, and 50 days after flowering. Seed coat samples were fixed in glutaraldehyde, and sections were stained with toluidine blue to be examined under a light microscope. Cell arrangements of desi and kabuli mature seed coats differed remarkably (Figure 9). Basic structures of both desi and kabuli seed coats resulted from differentiation of the outer integuments into distinct layers. In kabuli seed the subepidermis developed as a single layer of palisade-like cells without cell-wall thickening. The subepidermis of desi seeds developed into several layers of cells that later became thick-walled sclereids, which were heavily stained with toluidine blue, indicating the presence of phenolic compounds.

Plant Improvement

Breeding Methodology

F_5 progenies derived from random plants of F_4 bulks of single- and three- and four-way crosses among Annigeri, ICCC 1, ICCC 2, and K 850 were evaluated in a replicated trial at ICRISAT Center.

The trial was a nested lattice with 25 main treatments (6 single-, 12 three-, and 3 four-way crosses, and 4 parents) each consisting of 49 subtreatments—40 test progenies, 4 parents, and a control repeated five times. Detailed analyses are in progress but the frequency of high-yielding progenies was greater in multiple than in single crosses. We selected for further evaluation 380 progenies with numerically greater seed yields than the mean of the controls. The best yielders will be tested in a replicated trial.

Off-Season Nurseries

At ICRISAT Center, we conducted backcrosses for seed size and wilt resistance, obtained additional seed of crosses attempted in the main season, and multiplied seed of some entries in international trials. We also multiplied seed samples from outside India during the off-season in the postentry quarantine area (PEQIA). Included were 351 F_3 progenies of F_2 plants resistant to ascochyta blight and 48 ascochyta-resistant lines from ICARDA, and 3 accessions from Bangladesh. At Wadoora, a new site in Kashmir, 660 F_1s and nearly 600 F_3 and more advanced progenies and bulks were sown.

Breeding Desi Types

More than 400 crosses were made involving: line × tester sets of established and new cultivars; diallel series among new cultivars; and backcrosses to improve seed size.

More than 9000 populations and progenies were evaluated at ICRISAT Center and Hissar (Table 8). F_1 trials of line × tester and diallel series made in 1981/82 confirmed that variation in seed yield and its components is both additive and nonadditive.

In the early and medium-maturing categories, 235 F_2 and 114 F_3 bulks were evaluated in replicated trials at ICRISAT Center and Gwalior, and 82 late-maturing F_2s and 86 F_3s were evaluated at Hissar and Gwalior. In each maturity group, some populations produced significantly higher yields than the controls. The highest-yielding populations have been advanced for further testing and selection.

We also grew 6350 F_5 progenies at ICRISAT Center and 1974 at Hissar. Progenies with sufficient seeds were sown in two plantings. To vary the environment, at ICRISAT Center one sowing was under unprotected conditions and at Hissar the sowings were on different dates. From F_3 and F_4 populations and segregating progenies, we selected 7315 single plants at ICRISAT Center and 3816 at Hissar for further progeny tests; and 233 progeny bulks will enter international nurseries and replicated trials.

Nearly 300 germplasm accessions and breeding lines were evaluated in replicated trials at ICRISAT Center, Hissar, or Gwalior. And 14 entries were promoted to international trials and nurseries in 1983/84.

Breeding Kabuli Types

Twenty-four crosses between high-yielding and large-seeded cultivars were obtained. Single plants were selected in 24 F_2 populations from earlier crosses, and 32 entries were selected for

Table 8. Numbers of desi chickpea populations and progenies grown at ICRISAT Center and Hissar, 1982/83.

	ICRISAT Center		Hissar		Total	
Generation	1st planting	2nd planting	1st planting	2nd planting	1st planting	2nd planting
F_1	100	0	87	0	187	0
F_2	235	0	102	0	337	0
F_3	120	0	390[1]	0	510	0
F_4	58	0	77[2]	0	135	0
F_5	2343	1800	659	403	3002	2203
F_6	2603	2067	771	675	3374	2742
F_7	1404	951	223[3]	132	1627	1083
F_8	0	0	60	52	60	52
F_9	0	0	22	18	22	18
Total	6863	4818	2391	1280	9254	6098

1. 284 progenies and 106 populations.
2. 19 progenies and 58 populations.
3. 159 progenies and 64 populations.

further evaluation from 92 F_3 bulks in replicated trials at Hissar. Nearly 350 single plants and 60 progeny bulks were selected from about 1400 F_3 and more advanced bulks and progenies grown at Hissar; we also evaluated 133 lines in replicated trials there.

Extending Adaptation of Chickpea

Early sowing. Screening genotypes for adaptation to early sowing in peninsular India continued at ICRISAT Center.

F_1s of crosses between lines that had performed consistently well when sown early and those with wilt, root rot, and colletotrichum blight resistance were backcrossed to their adapted parents to incorporate disease resistance.

In an early-sown replicated trial of F_1s of a 7 x 7 diallel among adapted lines, variation in most characters was predominantly additive; P 1329 was the best general combiner for seed yield.

We advanced 32 F_1s and evaluated 20 F_2 and 10 F_3 populations of earlier crosses under early-sown conditions and selected 800 single plants for further evaluation as progeny rows next season.

We also tested 248 new germplasm accessions, grouped according to maturity, in four replicated trials sown early, and repeated the comparison of previously identified lines under early and normal sowing to identify adapted lines and characters important for early sowing. The best yields among early-sown accessions were from early to medium-maturing genotypes. High-yielding lines also had large seeds and produced many branches, pods, and seeds per plant.

Where comparisons were possible, early-sown chickpeas have yielded better than those sown at the normal time, under both irrigated and nonirrigated conditions, and several genotypes (notably P 1329, P 1067-1, P 18, and P 4089-1) have consistently produced higher seed yields than the control, Annigeri (ICRISAT Annual Report, 1981, p. 111).

In 1982/83, seed yields of early-sown chickpeas were again significantly higher than those of lines sown at the normal time (Table 9). When sown early, P 1329 produced 3 t/ha or more, significantly higher than Annigeri in two of three comparisons. The seed yields of P 1067-1 and of normal-sown P 1329 did not differ significantly from those of Annigeri. P 1329 is capable of performing well across a range of sowing dates, an important characteristic for rainfed situations where sowing date is determined by when rains cease; it has been contributed to coordinated trials in 1983/84.

Late sowing in northern India. We continued efforts at Hissar to identify genotypes suited for late sowing, to fit into established rotations with

Table 9. Seed yields (kg/ha) of 3 chickpea cultivars in early and normally sown trials under irrigated and nonirrigated conditions, ICRISAT Center, 1982/83.

	Trial 1 nonirrigated		Trial 2 irrigated		Trial 3 nonirrigated		
Cultivar	Early	Normal	Early	Normal	Early	Normal	Mean
P 1329	3020	2410	3660	2980	1820	900	2460
P 1067-1	2570	1950	3290	3170	1760	800	2260
Annigeri	2460	2280	3000	2890	1770	730	2190
SE	±107		±224		±132		
Mean[1]	2390	1770	3200	2880	1560	710	
SE	±83		±112		±60		

[1] Trial mean.

rice, cotton, and other crops. We selected 800 single plants in more than 600 F_3 to F_5 progenies. In collaboration with the physiologist, we sowed 480 unreplicated germplasm accessions late; promising entries will be included in replicated trials in 1983/84. In a preliminary yield trial of germplasm accessions and cultivars sown late, four entries produced significantly more seed yields than H 208. The highest yield (2940 kg/ha) was from GG 550, developed at Gurdaspur (PAU). Forty-five desi and 23 kabuli genotypes, which had previously performed well in late-sown conditions, were also evaluated in replicated trials. Three lines (ICCC 14 and 41, and NEC 989), which have performed consistently well and have some resistance to ascochyta blight, will be contributed to late-sown coordinated trials.

Plant Type

Tall, erect habit. Breeding for improved yield potential of tall, erect types continued. Since many crosses involving tall types have already been made, we made only 16 new combinations in 1983—to initiate backcross series to improve yields and to incorporate resistance to both fusarium wilt and ascochyta blight.

We could not achieve many of the combinations attempted in 1982 in the 9 × 8 line × tester sets, so we advanced 51 F_1s in nonreplicated plots.

Table 10. Plant heights and seed yields of tall chickpea types compared with H 208, K 850, and Pant G 114, Hissar, 1982/83.

Line/cultivar	Plant height (cm)	Seed yield (kg/ha)
750112-2H-2H-1P-1H-1H-BH	86.8	2520
770377-BH-1H-BH	77.5	2480
750110-2H-1H-1P-2H-1H-BH	94.8	2470
750102-6H-1P-1P-1H-BH-BH	78.0	2470
H 208	64.0	1820
K 850	57.5	1760
Pant G 114	64.0	1690
SE	±4.21	±229
Mean	80.4	2000
CV (%)	10.5	23

At ICRISAT Center, 53 F_2 populations and 1082 F_3 to F_8 progeny rows were grown, and 780 single plants and 23 rows were selected. At Hissar, we selected 2237 single plants and 39 rows from 86 F_2 populations and 1633 progenies.

Replicated trials of advanced tall lines were sown at ICRISAT Center and Hissar. At ICRISAT Center, the tall types all flowered later than Annigeri, the adapted control, and none yielded significantly more than the control though stands and yields varied widely. At Hissar, stand and growth were good, and three of the tall lines produced significantly more seed than the best adapted control H 208 (Table 10).

Double-podded and multiseeded types. Selection to combine the double-podded and multiseeded characteristics with high yield continued. Using line × tester mating designs, we made 64 crosses involving four newly identified double-podded and wilt-resistant lines, six multiseeded lines, and eight new early- and late-maturing high-yielding desi cultivars.

In a replicated trial of F_2s of a 5 × 5 diallel cross among multiseeded lines at ICRISAT Center, variation in all characteristics except seed yield, but including seeds per pod, was predominantly additive. HMS 6 was a good general combiner for plant height and branch number; HMS 5 and 13, for seeds per pod; and HMS 5, for pods, seeds, and seed yield per plant.

We grew 88 F_2 to F_4 populations and 1815 F_3 to F_5progenies at ICRISAT Center; the corresponding figures at Hissar were 82 and 1119, respectively. We selected 5300 single plants from the populations. Means and ranges for seeds per pod and seed yields among the progenies were much greater than among controls (Table 11), so seed yields may be improved by selecting for multiseeded and double-podded characters. We selected 1500 plants at ICRISAT Center and 1100 at Hissar that combined those two characters with good seed yield.

For the first time at ICRISAT Center plants with pods having more than six seeds were recorded in progenies grown without insecticide

Table 11. Means and ranges for seeds/pod and seed yield among multiseeded and double-podded chickpea progenies, ICRISAT Center, 1982/83.

Generation	Seeds per pod			Seed yield (kg/ha)		
	No	Range	Mean	No	Range	Mean
F_3 progenies	1067	1.02-2.66	1.58±0.216	150	521-2004	1240±132
Annigeri	56	1.05-1.78	1.50±0.113	47	531-1729	1170±152
K 850	55	1.15-1.84	1.33±0.120	47	552-1708	940±128
F_4 progenies	546	1.09-2.73	1.73±0.254	84	729-1989	1240±143
Annigeri	29	1.23-1.82	1.49±0.119	30	448-1479	1060±171
K 850	29	1.06-1.51	1.31±0.254	29	542-1583	980±176
F_5 progenies	66	1.03-2.21	1.57±0.232	66	432-1459	780±183
Annigeri	10	1.32-1.58	1.46±0.090	10	344-1010	630±238
K 850	10	1.26-1.65	1.39±0.128	10	375- 875	650±157

protection. The extra seeds may have resulted from increased photosynthate as early-formed pods were lost through insect damage. The multiseeded character may compensate for pest damage and offer another factor important in research and selection. Further studies of multiseeded and double-podded progenies will be conducted in collaboration with physiologists.

Cooperative Activities

In 1983, materials distributed to cooperators continued to increase. We further refined materials grouping for specific situations by introducing F_2 and F_3 trials and international screening nurseries in the medium-maturing category and initiating a program to incorporate gray mold resistance in early-maturing cultivars for the northeastern sector of the Indian subcontinent. F_2 and F_3 trials in the late-maturing category were not formulated for fear of spreading ascochyta blight with the seed.

International Trials and Nurseries

We distributed 155 sets of international trials and nurseries of breeding materials to 49 cooperators in 15 countries (Table 12).

As in previous seasons, few F_2 or F_3 populations produced significantly heavier yields than the controls at individual locations, but some were significantly better overall.

In the International Chickpea Screening Nurseries (ICSNs), entries at individual locations performed better than controls. Best yielders overall were ICCL 82230 (early maturing), ICCL 82119 (medium maturing) and ICCL 82445 (late maturing). In ICCT-DS (International Chickpea Cooperative Trial—Desi Short duration), an ICRISAT entry (ICCL 81018) from a cross of H 208 and NP 34 ranked first and ICCC 37 (previously ICCL 80074), which produced the heaviest yield in coordinated trials, ranked second. In ICCT-DL (International Chickpea Cooperative Trial—Desi Long duration), Pant G-114 produced the most seed and GL 769 was second. Two new entries (ICCC 39 and 40) have been contributed to coordinated trials in 1983/84.

The adaptation trial was continued for a second year in collaboration with ICARDA; 19 sets were supplied by ICRISAT and more than 50 were distributed from ICARDA. The data are still being assembled for analyses, but preliminary examination suggests that the yield potential of desi cultivars generally exceeds that of kabulis.

Outside India, several cultivars selected from ICRISAT materials are in on-farm tests or prerelease stages. They include: IC 7357-2-3-1H-BH, being proposed for release in Australia; IC

73129-16-3-B-BH, in on-farm tests in Ethiopia; and ICCC 4 and IC 73167-5-3-1P-BH, in on-farm tests in Nepal.

Distribution of Breeders' Material

We also supplied seeds of 2995 breeding lines and segregating populations to breeders in India and elsewhere.

Cooperation with AICPIP

In the Gram India Evaluation Trial (GIET), three (ICCC 35, 37, and 38) of the four ICRISAT entries appeared among the top five yielders in the peninsular zone and ICCC 37 ranked first. All three were promoted to the next stage of testing and ICCC 36 was retained in GIET for another year. ICCC 22, 27, 28, 29, and 30 and P 326 performed well in Gram Coordinated Variety Trial (GCVT) and all of them were retained for another season. ICCC 32 which ranked first in seed yield in the kabuli trials, and ICCC 25 and 34 (a new entry) were retained for another year.

In addition to entries contributed directly by ICRISAT to AICPIP trials, many entries selected from ICRISAT materials are contributed by other institutions, and many ICRISAT entries are in state trials. ICCC 4 has now been released in Gujarat by the State Variety Release Committee after several years of tests in that state: 400 kg of breeders' seed of ICCC 4 was supplied to Gujarat for initial multiplication.

Cooperation with ICARDA

ICRISAT has stationed two chickpea scientists at ICARDA to work on kabuli chickpeas for spring and winter sowing in the Mediterranean region of western Asia, northern Africa, and southern Europe, and in the Americas. Most of the work reported here was carried out by them, in collaboration with national programs and with chickpea scientists at ICRISAT Center.

Plant Improvement

The 11 F_2 populations of crosses made in 1981/82 involving ICC 72, 262, and 3279 were

Table 12. International chickpea trials and nurseries distributed by ICRISAT in 1982/83.

Country	F_2MLTDS	F_2MLTDM	F_1MLTDS	F_1MLTDM	ICSNDS	ICSNDM	ICSNDL	ICCTDS	ICCTDL	ICAT	Total
Bangladesh			1		4			2			7
Bulgaria										1	1
Burma					1			1			2
Cameroon										1	1
Canada						1	1	1	1		4
Ethiopia					1	1					2
India	5	5	8	10	11	15	12	15	11	16	108
Kenya					1	1					2
Malawi								1	1	1	3
Nepal							1				1
Oman								1	1		2
Pakistan		2				3	7		7		17
Philippines								1			1
Tanzania								1			1
Zambia					1						1
Total	5	7	9	10	19	21	21	23	21	19	155

MLT = Multilocation Trials.
DS = Desi Short-duration.
DM = Desi Medium-duration.
DL = Desi Long-duration.
ICSN = International Chickpea Screening Nursery.
ICCT = International Chickpea Cooperative Trial.
ICAT = International Chickpea Adaptive Trial.

Harvesting of ICRISAT's chickpea ICCC 4 in Gujarat, India, where it has been released to farmers after several years of testing. Some 400 kg of its seed was supplied to Gujarat for multiplication.

screened for ascochyta blight resistance at ICARDA. Bulked seed of resistant plants of these and other crosses made at ICARDA were supplied to Pakistan, and seeds of resistant plants were returned to ICRISAT Center, where they were multiplied under rain shelters during the off-season. We also multiplied seeds of the Chickpea International Ascochyta Blight Nursery (CIABN-83) and of other materials with resistance to ascochyta blight supplied from ICARDA.

Table 13. Mean performance of chickpea cultivars in on-farm trials in Syria, winter and spring seasons 1982/83.

	Yield (kg/ha)[1]		Winter yield gain (%)	
Cultivar	Winter	Spring	cf Spring	cf Syrian local
ILC 195	1620	1000	62	48
ILC 202	1590	1020	55	45
ILC 482	2020	1370	48	85
ILC 3279	1650	1070	53	51
ILC 1929 (control)	NS	1090		

1. Mean of 24 locations. NS = Not sown.

Promising kabuli lines bred at ICRISAT were compared with ICARDA materials in two replicated trials at Aleppo; and several produced seed yields similar to those of the best control, ILC 1929.

On-farm trials with winter sowing in Syria. Three genotypes, ILC 195, 202, and 3279, were tested against ILC 482 during winter, and four genotypes, ILC 195, 202, 482, and 3279, were tested against a Syrian landrace during spring (Table 13). ILC 482 produced the highest yield during both winter (2020 kg/ha) and spring (1370 kg/ha); it is a cultivar already recommended for winter sowing in Syria.

ILC 3279 has more ascochyta blight resistance and cold tolerance than ILC 482, and being 50% taller, it is more suitable for mechanical harvest, of special appeal to farmers. In on-farm trials for two years its 1640 kg/ha average grain yield ranked second, immediately after ILC 482. The Ministry of Agriculture has identified it as a promising cultivar for possible release in Syria after the 1983/84 season. Anticipating its release, they asked us to multiply seed.

International yield trials. During 1982/83, we furnished 318 sets of 9 nurseries in 45 countries. Results thus far returned are of interest to cooperators.

In the 1980/81 spring-sown Chickpea International Yield Trials (CIYT) at 14 locations, ILC 295 and ILC 463 ranked first and second. Three-year results showed ILC 295 best, followed by ILC 237. In the winter-sown Chickpea International Yield Trial-Winter (CIYT-W), ILC 200 and ILC 195 were the two top yielders when averaged at 29 locations. But in 3-year average results, ILC 482 is still number one. In the Chickpea International Yield Trial, Large-seeded (CIYT-L), ILC 116 was the highest yielder, followed by ILC 171. ILC 464 was first the previous season and on an average of two years.

Promising materials from the international nurseries have been selected and included in multilocational or on-farm trials by 11 national programs including Canada, Cyprus, Egypt, Jordan, Lebanon, Morocco, Pakistan, Sudan, Syria, Tunisia, and the USA. After initial testing, a few lines have been identified for prerelease multiplication and large-scale testing in five national programs: (a) Syria ILC 3279; (b) Lebanon, ILC 482; (c) Jordan, ILC 484, and 202; (d) Cyprus, ILC 3279; and (e) Morocco, ILC 195, 482, and 484.

Hybridization. A total of 375 crosses were made during 1982/83 at Tel Hadya: 109 crosses for development of cultivars for winter and spring sowing, 30 for large-seeded cultivars, 25 for tall types, 25 for large-seeded and tall cultivars, 12 for cold tolerance, 20 to improve local landraces, 48 for the national programs in Tunisia and Jordan, 66 to identify and pyramid genes for resistance to ascochyta blight, and 40 for inheritance studies on height and seed size, cold tolerance, protein content, iron chlorosis, and resistance to leaf miner. Of the 375 crosses, 326 were single crosses, 45 three-way crosses, and 4 backcrosses.

As the main focus of the program is to develop high-yielding and ascochyta blight resistant genetic stocks, one parent in all crosses was ascochyta blight resistant.

Segregating populations. The F_2 to F_4 generations were grown in the ascochyta blight disease nursery during winter at Tel Hadya. The F_5 to F_7 generations were grown during both winter and spring for selection at Tel Hadya. The F_1, F_3, and

Table 14. Segregating chickpea material grown for winter (W) and spring (S), and plants selected at Tel Hadya (1982/83 main season) and at Sarghaya, Syria, (1982 off-season).

	No. of materials		No. of plants selected	
Generation	Main season	Off-season	Main season	Off-season
F_1		191		6856[1]
F_2 populations	179	15	3312	-
F_3 bulks	27	-	505	-
F_3 progenies	2310	1007	1541	1212
F_4 W	1219	1099	426	1830
F_5 S	228	-	126	-
F_5 W	2243	-	586	-
F_6 S	510	-	222	-
F_6 W	751	-	201	-
F_7 S	372	-	-	-
F_7 W	547	-	-	-

1. To eliminate selfed plants, single plants are harvested in F_1 and plant rows grown in F_2.

Table 15. Chickpea entries exceeding yield of controls in advanced yield trials (AYT) and preliminary yield trials (PYT), Tel Hadya, Syria, spring 1982/83.

	No. of test entries exceeding control			Highest yield	Percentage of control			CV
Trial	ILC 482[1]	ILC 263[2]	ILC 1929[3]	(kg/ha)	ILC 482	ILC 263	ILC 1929	(%)
AYT-1	21	0	0	1760	152	95	98	16.0
AYT-2	14	2	2	1700	157	109	110	20.2
AYT-3	5	1	0	1420	110	101	97	11.5
AYT-4	6	0	0	1250	108	90	94	12.5
PYT-1	4	0	0	1440	118	98	95	23.7
PYT-2	1	1	0	1540	101	108	93	24.3
PYT-4	13	1	1	1040	127	108	106	24.5
PYT-5	1	1	1	1430	110	107	111	27.3
PYT-16	5	2	3	1260	98	107	110	21.3
PYT-7	1	14	15	1550	112	127	137	18.2
PYT-8		5	2	1460	102	116	111	17.5

1. ILC 482 = released cultivar in Syria.
2. ILC 263 = high-yielding line in spring.
3. ILC 1929 = Syrian landrace.

advanced generations were grown at Sarghaya during the off-season. The total segregating material grown during 1982/83 is shown in Table 14.

Breeding for spring sowing. A total of 273 newly developed lines with blight resistance were evaluated in five advanced yield trials (AYT) and eight preliminary yield trials (PYT) during spring season at Tel Hadya, with three controls in each trial. Only 10 entries exceeded all three controls (Table 15). At Terbol 189 lines were tested in 5 AYTs and 4 PYTs; their performance was better than at Tel Hadya, with 28 lines exceeding all three controls (Table 16).

Breeding for winter sowing. We also evaluated the 273 lines tested in 5 AYTs and 8 PYTs at Tel

Table 16. Chickpea test entries exceeding yield of controls in AYT and PYT, Terbol, Syria, spring 1982/83.

	No. of test entries exceeding control			Highest yield	Percentage of control			CV
Trial	ILC 482[1]	ILC 263	ILC 1929	(kg/ha)	ILC 482	ILC 263	ILC 1929	(%)
AYT-1	0	5	0	1940	100	111	97	17.0
AYT-2	0	4	2	2040	99	106	101	16.0
AYT-3	6	3	15	2320	116	108	128	16.0
AYT-4	0	0	9	2150	92	99	112	12.0
AYT-5	3	0	1	2180	108	94	103	14.2
PYT-1	9	21	5	2260	115	154	107	19.0
PYT-2	5	2	10	2680	130	125	138	19.0
PYT-3	17	9	8	2060	122	112	110	20.0
PYT-4	10	18	11	2280	123	136	129	23.0

1. See footnotes in Table 15.

Table 17. Chickpea entries exceeding yield (kg/ha) of controls in AYT and PYT, Tel Hadya, Syria, winter 1982/83.

Trial	No. of test entries exceeding control		Highest yield (kg/ha)	Percentage of control		CV (%)
	ILC 482	ILC 3279		ILC 482	ILC 3279	
AYT-1	21	11	2610	166	177	16.3
AYT-2	21	14	2310	164	126	17.0
AYT-3	21	15	2410	202	129	17.5
AYT-4	19	6	2630	150	109	15.3
AYT-5	21	7	2460	184	109	12.4
PYT-1	21	20	2970	221	158	19.3
PYT-2	14	17	2600	146	166	21.1
PYT-3	19	4	2920	169	115	17.6
PYT-4	10	5	2080	119	111	17.9
PYT-5	19	10	2550	191	129	24.3
PYT-6	21	13	2800	202	130	19.7
PYT-7	15	13	2810	157	150	14.0
PYT-8	20	17	2600	152	127	18.9

Hadya for yield and adaptation when winter sown, with the same three controls in each trial of 24 entries. A total of 242, 152, and 273 entries exceeded ILC 482, ILC 3279, and ILC 1929, with ILC 1929 totally killed by ascochyta blight (Table 17). The top entries generally yielded between 2500 and 3000 kg/ha, exceeding ILC 482 by 50 to 121%. At Terbol 189 lines were tested in 5 AYTs and 4 PYTs against the same three controls. A total of 56, 53, and 62 entries exceeded ILC 482, ILC 3279, and ILC 1929 (Table 18). Highest-yielding entries produced between 2730 and 3650 kg/ha. Most of the new lines resisted ascochyta blight and cold better than ILC 482.

Breeding for large seed. Progress in breeding large-seeded, high-yielding, ascochyta blight resistant lines has been slow because resistant sources have small seeds. But we developed nine lines with seeds exceeding 40 g/100 and tested them in an advanced yield trial for large-seeded types during winter and spring at Tel Hadya. During winter only 7 entries outyielded ILC 482; 9 out-

Table 18. Chickpea entries exceeding yield (kg/ha) of controls in AYT and PYT, Terbol, Syria, winter 1982/83.

Trial	No. of test entries exceeding control			Highest yield (kg/ha)	Percentage of control			CV (%)
	ILC 482	ILC 3279	ILC 1929		ILC 482	ILC 3279	ILC 1929	
AYT-1	12	5	11	2730	117	107	115	20.4
AYT-2	2	6	6	2880	106	112	111	17.0
AYT-3	1	1	9	2810	100	107	118	15.0
AYT-4	1	6	1	3170	100	109	103	9.4
AYT-5	3	8	10	2840	109	116	121	17.0
PYT-1	15	8	9	3070	128	105	105	13.0
PYT-2	7	4	9	3650	123	119	128	15.0
PYT-3	14	10	7	3500	120	115	112	14.0
PYT-4	1	5	0	3490	103	112	99	13.4

yielded ILC 464; and 5 outyielded ILC 3279. Maximum yield recorded was 2460 kg/ha. Only one entry was better (1480 kg/ha) than the large-seeded control (ILC 464) in spring. Syria's national program has identified two large-seeded types, ILC 620 and 629, for on-farm trials during 1983/84.

Breeding for tall type. An AYT of tall types was conducted with 21 newly bred entries and 3 controls (ILC 482, 3279, and 1929) during winter and spring. Nine entries yielded more than the tall control ILC 3279; highest yielding entries produced 121% of the control. FLIP 82-83 showed many advantages. It was tall, true kabuli, its 100-seed wt was 36 g, and it resisted ascochyta blight.

Leaf miner resistance. Leaf miner *Liriomyza cicerina* is the major pest in the Mediterranean region. During 1982/83, of 3367 lines evaluated, 13 were resistant to leaf miners (Table 19). Some lines, ILC 726, 1776, and 3350 retained resistance shown the previous year.

Cold tolerance. The 366 lines identified as cold tolerant during the 1981/82 season were sown 23 October along with susceptible controls at Tel Hadya for the 1982/83 winter season. The 23 October sowing (1 month before normal winter sowing) was to permit more growth before severe cold weather. Subzero temperatures were recorded 53 nights during the crop growth period—the coldest cropping season in 50 years. Ten lines were identified as highly tolerant: ILC 2487, 2505, 3698, and 3789 from India; ILC 666, 668, and 1071 from Iran; ILC 3081 and 3787 from Pakistan; and ILC 3470 from Spain. Earlier screening at Hymana near Ankara in Turkey revealed that lines originating from the Indian subcontinent were most cold tolerant.

A set of genotypes ranging from highly susceptible to highly tolerant were sown with susceptible controls on nine sowing dates from 23 October 1982 to 9 March 1983, at 10- to 20-day intervals. Cold injury was pronounced in plants sowed earliest (23 October), with injury observed for the four earliest sowings.

Table 19. Resistance of kabuli chickpea germplasm accessions to leaf miner, Tel Hadya, Syria, 1981/82 and 1982/83.

Visual damage scores[1]	1981/82	1982/83
1	0	0
3	13	13
5	80	76
7	381	691
9	1030	2587

1. 1 = highly resistant; 3 = resistant; 5 = tolerant; 7 = susceptible; 9 = highly susceptible.

***Orobanche* resistance.** Our 1982/83 screenings showed 11 lines highly resistant to the parasitic weed *Orobanche* in winter-planted chickpea. They are ILC 229, 280, 348, 351, 613, 170, 192, 205, 4074 and FLIP 81-61 and FLIP 81-293. Those lines had been identified for resistance during 1981/82 screenings in a naturally-infested field.

Genetic resources. The Kabuli Chickpea Gene Bank at ICARDA currently holds 5340 accessions; of these 920 were added in the past year, and 840 were developed at ICARDA through hybridization. The collection represents 34 countries, and is mainly from, in decreasing order: Iran, Afghanistan, Turkey, Chile, Spain, Tunisia, and India. We need to fill gaps in our collection from Morocco, Algeria, and Mexico.

More than 3300 collections have been evaluated for 27 descriptors. Evaluation data and passport information have been computerized, published as a Kabuli Chickpea Germplasm Catalog, and distributed to scientists. Additional collections from the USSR could be useful for ascochyta blight and frost resistance, late flowering, and tallness; from Spain for large seed size with high yield; from Chile for more primary and secondary branches, high harvest index, and high protein content; and from the Indian subcontinent for cold tolerance.

A total of 6274 germplasm lines have been distributed (Table 20).

Table 20. Distribution of kabuli germplasm accessions to indicated national programs from ICARDA/ICRISAT cooperative chickpea program.

Country	No. of accessions
Canada	180
Chile	200
Egypt	500
Ethiopia	150
France	60
Jordan	62
Lebanon	60
Mexico	125
Morocco	600
Pakistan	780
Turkey	753
USSR	60
USA	661
Others	2083[1]
Total	6238

[1] Includes 1833 accessions sent to ICRISAT Center.

Diseases

Situation in West Asia and northern Africa. In Syria, ascochyta blight was the major disease in winter-sown chickpeas. In the spring-sown crop, some root rot due to *Rhizoctonia solani* was observed during early stages of crop growth. Later in the season ascochyta blight was severe in northern Syria. Some incidence of stunt and bean yellow mosaic virus disease was observed in both winter- and spring-sown crops. The incidence of bean yellow mosaic in winter chickpea this season was higher than in the past 3 seasons. The incidence of nematodes (root knot, cyst, and *Pratylenchus*) was observed in some fields in both winter- and spring-sown crops. We also observed isolated occurrence of the parasitic weeds, *Orobanche* in the winter-sown crop and *Cuscuta* in the spring-sown crop.

In Jordan, ascochyta blight was serious in winter-sown crops at the experimental stations. Farmers' fields contained up to 5% stunt and other viral diseases. Symptoms of *Pratylenchus* damage were seen in the winter-sown crop at the experimental stations.

In Tunisia, wilt and stunt were the major diseases. Up to 50% wilt was observed in certain fields (average 7%) and the incidence of stunt was as high as 40% in some fields (average 3.4%). Salinity damage, which killed plants in patches and was earlier confused with wilt, was observed throughout the area.

Seedling screening for blight resistance. We found the following method effective for rapid evaluation of seedlings for resistance to blight in the greenhouse. Sow 10 seeds of each accession in shallow iron trays or pots maintained at 15 to 20°C. When the seedlings are 10-15 days old, spray them with the spore suspension of 10- to 15-day-old fungus culture (100 thousand spores/ml) grown on chickpea dextrose broth (40 g chickpea seed meal, 20 g dextrose, 1 liter water). Cover groups of the trays or pots with low plastic cages (no higher than 1m) for 10 days, time by which susceptible lines are killed.

Field screening for blight resistance. The disease nursery was sown at the beginning of the rainy season between mid-November and December. The susceptible Syrian local chickpea (ILC 1929) was planted after every 2 to 15 test rows as an indicator-cum-spreader row. The nursery was inoculated with a mixture of four races (races 1, 2, 3, and 4) from Syria during both the vegetative and podding stages of crop growth. During dry spells in March, April, and May, sprinklers were operated 1 to 2 hr/day to increase relative humidity. Disease development was severe, killing all indicator rows, and 100% pods on susceptible cultivars were infected. We hope to select lines with durable resistance by screening F_2, F_3, and F_4 generations.

Screening kabuli germplasm for blight resistance. None of 468 new germplasm accessions primarily from Tunisia and Jordon screened in the field against races 1, 2, 3 and 4 was resistant or tolerant.

Additional sources of blight resistance. Seventy germplasm accessions of both kabuli and desi types that were resistant or tolerant at Tel Hadya during 1981/82 were retested this year at a more humid (rainfall 1000 mm) coastal site in Lattakia where severe epiphytotic blight develops.

Considering vegetative and pod infection at both locations six lines: ILC 3856, 3864, and 3870; ICC 9514, Pch 70, and CAM 72, were rated resistant. Seventeen lines showed tolerance at both locations: ILC 3803, 3866, and 3868; ICC 4181, 8486, 9189, 9501, 11871, and 12023; Pch 70, and 124; CAM 66, 67, 68, 94, and 96; and Sel 80 Tr 52004.

Chickpea International Ascochyta Blight Nursery (CIABN-83). Fifty entries of kabuli and desi germplasm accessions and kabuli lines developed through hybridization at ICARDA were tested through CIABN-83 in blight-endemic countries to identify resistant lines and lines with race nonspecific resistance. They were resistant at ICARDA in two previous seasons.

Most of the lines showed resistance during the vegetative stage at Tel Hadya and Lattakia, but resistance of only 11 lines held through podding stages at both locations. They are ILC 72, 187, 2380, 2506, 2956, 3279, 3346, and 3858; ICC 6262, and 6304; and Pch 15.

Seventeen lines showed tolerance at both locations: ILC 182, 183, 191, 195, 196, 200, 201, 202, and 3274; FLIP 81-51 W; ICC 3932, 4475, 6306, 6945, 6988, and 6989; and NEC 138-2.

Screening germplasm for resistance to a virulent race. Efforts to identify sources of resistance against a more virulent isolate (race 6) of *A. rabiei* were made among lines found resistant to race 3 at Tel Hadya and among kabuli germplasm accessions available at ICARDA.

Table 21. Reaction of a set of 6 differential chickpea genotypes to races of *Ascochyta rabiei*.

Differential genotype	Blight reaction					
	race 1	race 2	race 3	race 4	race 5	race 6
ILC 1929	S	S	S	S	S	S
F 8	R	S	S	S	S	S
ICC 1903	R	R	S	S	S	S
ILC 215	R	R	R	S	S	S
ILC 3279	R	R	R	R	S	S
ICC 3996	R	R	R	R	R	S

R = resistant, S = susceptible.

Of 16 lines resistant to race 3 last season, 3 (ICC 3996, and 6988; and ILC 3856) were resistant during the vegetative stage, and 5(ICC 3840, 3969, 4324, 4475, and 6981) were tolerant.

Only 2 of 48 lines with previous promise against race 6 were resistant this year. They are ILC 187 and 202. Two other lines, ILC 193 and 3346, were tolerant.

Testing 3000 additional kabuli germplasm accessions gave us 8 lines with promise (ILC 187, 193, 202, 1894, 2496, 2578, 2659, and 3346).

Physiologic races of *Ascochyta rabiei*. Fifty samples of chickpea affected by blight were collected from Syria and Lebanon in 1981/82 season from both winter- and spring-sown crops. When cultivated and widely tested this year, isolates showed a large variation in colony growth rate, sporulation, and pycnidial size. Based on those characters, the 50 samples were divided into 24 groups. Except for group 4, all were highly pathogenic; they varied largely in virulence. Based on disease reaction, the 24 groups were reclassified into 6 distinct races (Table 21).

The less virulent races 1 and 2 were recovered only from the susceptible landraces grown in farmers' fields. The more virulent races (3,4,5, and 6) were isolated mostly from resistant lines at the experimental sites. The prevalence and distribution of the most virulent race 6 in other parts of the world is not known. A collaborative project between ICARDA and the University of Reading, UK, will try to determine the extent of variability in the fungus in the blight-endemic countries.

Epidemiology. Blight development in susceptible cultivar ILC 464 was closely related to temperature (Fig. 10). The disease began to develop when average minimum temperature exceeded 5°C, and average maximum temperature, 15°C. It almost killed the plant in a 3-week period when maximum temperature rose from 15 to 25°C.

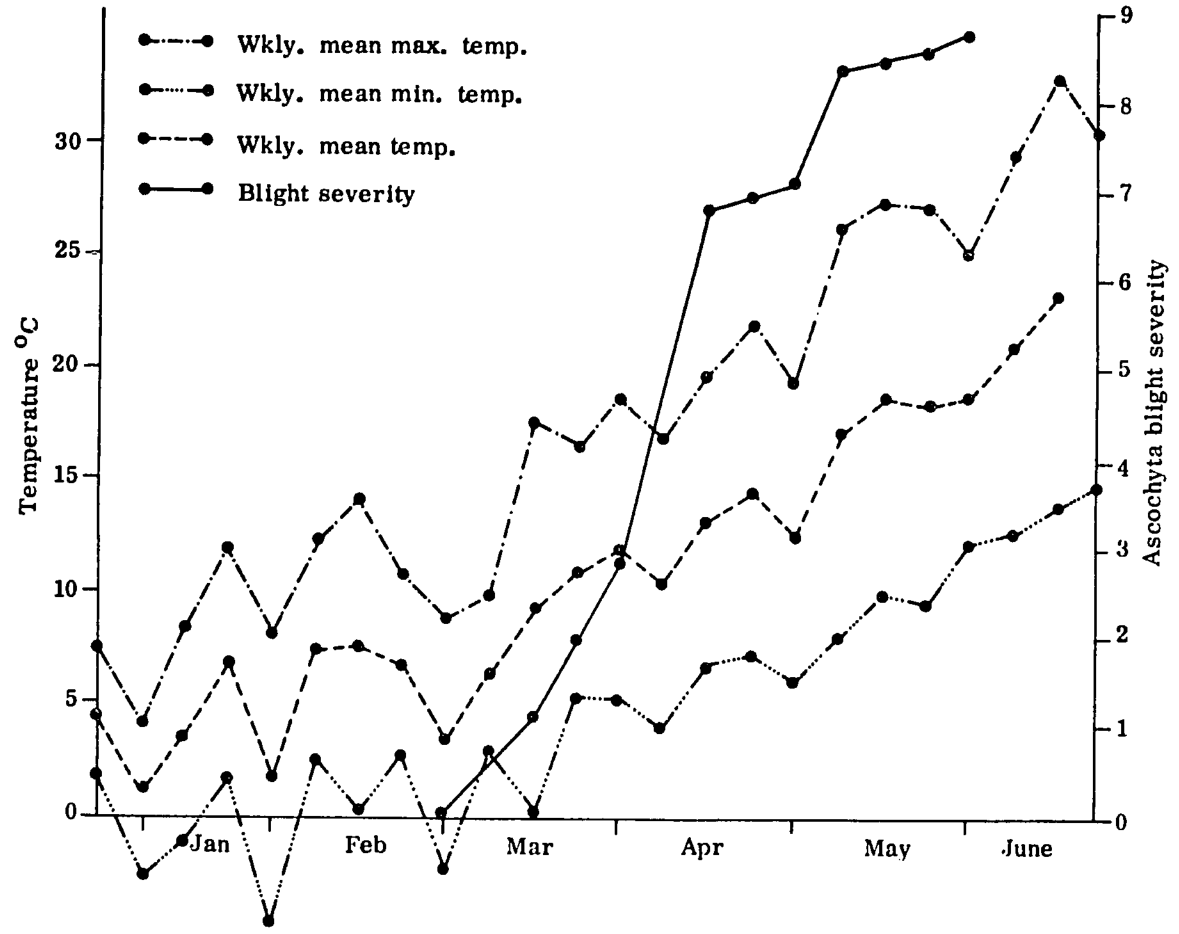


Figure 10. Development of ascochyta blight in chickpea in relation to temperature, Tel Hadya, 1982-83.

Types of blight resistance. Blight incidence and severity were also estimated throughtout the season in three cultivars in a field experiment. In ILC 464, both extent of infection and severity were high. In ILC 482, extent of infection was as high as the susceptible cultivar, but severity was low. In ILC 3279, both infection percent and severity were low. Different types of resistance are indicated in ILC 482 and ILC 3279.

Fungicidal seed dressing for ascochyta blight. Calixin M® (11% tridemorph + 36% maneb), which effectively eradicated seedborne inoculum in earlier experiments, was used for general seed dressing. But the 6 g/kg doses needed to eradicate the pathogen are slightly phytotoxic and predispose plants to cold injury and root rots. When we tested it and a few other fungicides in 1983, Thiabendazole (Tecto 60®) proved superior, preventing above-ground infection completely at 3 and 6 g/kg without any phytotoxic effect.

Multiple disease resistance. Though the present emphasis is on ascochyta blight, which is the major disease problem in spring- and winter-sown chickpeas in the region, we are trying also to develop resistance to other potentially dangerous diseases such as wilt, root rots, and stunt.

For three seasons now, lines identified elsewhere as having resistance to wilt (*Fusarium oxysporum*) and root rots (mainly *Rhizoctonia*

Table 22. Reaction of some wilt and root rot resistant chickpea lines to ascochyta blight at Tel Hadya, Syria, 1982/83.

	Ascochyta blight score on 1-9 scale	
Genotype	Vegetative stage	Podding stage
ICC 1881	4	6
ICC 1963	4	5
ICC 4935	3	6
ICC 89301	2	5
ICC 89300	4	7
G 543	3	5
G 668	2	5

bataticola) have been screened against ascochyta blight. Reaction of seven lines retested this year from material found promising the previous year or two is given in Table 22. All seven lines had acceptable levels of resistance at the vegetative stage, but proved susceptible at the podding stage.

At Beja experimental station, Tunisia, severe natural attack of wilt occurred in plots where the winter and spring chickpea trials were sown. A few of the Tunisian local lines/selections and some from the ICARDA/ICRISAT joint program showed good tolerance to wilt. Lines resistant to blight should accelerate development of lines with combined blight and wilt resistance.

Workshops, Conferences, and Seminars

Consultative Group Meeting for Asian Regional Research on Grain Legumes

Forty-eight participants representing research organizations in India, Indonesia, Japan, Malaysia, Nepal, Pakistan, Philippines, Thailand, ICRISAT and other international organizations with responsibilities for agricultural development in Asia met 11-15 December, at ICRISAT Center, to discuss ways that ICRISAT can help improve groundnut, chickpea, and pigeonpea production in the region, because production has fallen well below demand.

The group agreed that a coordinated regional approach to research would be productive, and that an operational network of scientists and policymakers should be established. Particular attention should be paid to crop improvement and related cropping systems and socioeconomic research. Improvements are also needed in transfer of germplasm between research centers, training research staff, and exchange of information and advice, particularly among visiting specialists. The group's recommendations and executive summaries of the papers presented are available from Information Services, ICRISAT.

Group Discussion on Pulse Pest Management

Twenty-five pulse entomologists from India, Jordan, Pakistan, Thailand, USA, ICARDA, and ICRISAT assembled at ICRISAT Center, 5-10 December, to share their experience and to plan for future research and development of pest management on chickpea and pigeonpea. The discussions focused on host plant resistance, survey and surveillance, insecticide use, biological and cultural control, and the investigation of pest management and its adoption. Participants indicated the following requirements for work in India: standard methodology for surveillance and in selecting for host plant resistance; an illustrated handbook for pest recognition; and determined efforts to use available natural control elements. It was agreed that an operational research project concerning village-level pulse pest management or management of a large area has high priority.

Chickpea Breeders' Meets

Twenty-two breeders from southern and central India, and one from California, USA, attended the meet held at ICRISAT Center, 2-4 February. Another meet was held at Haryana Agricultural University (HAU) Hissar, 4-6 April, in which 17 breeders from other Indian centers, HAU, and ICRISAT participated. The breeders selected material from ICRISAT plots for trials at their own locations.

Looking Ahead

Benefits of our past work gathered momentum in 1983 with a chickpea cultivar bred at ICRISAT approved for release to farmers. Other similar worthwhile improvements are also in progress. Genotypes that combine disease and insect resistance should soon be available for multilocation testing. Successful ones should be particularly valuable to the many farmers who cannot afford costly plant protection measures.

Drought tolerance by genotypes of diverse origin will be evaluated in the field under long-day treatments to eliminate differences in maturity. Field screening germplasm for ability to germinate and emerge from limited seedbed moisture will be undertaken. Greater emphasis will be placed on characterizing growth and development of new breeding lines.

Work will continue on the adapted genotypes selected and advanced for late planting, and commence on a laboratory technique to test for genotypic differences in tolerance to salinity.

Emphasis on locating sources of resistance to ascochyta blight and botrytis gray mold will continue, with increased attention to incorporating available sources into improved backgrounds for northern areas of India. We will continue to study the race situation in *F. oxysporum* f.sp. *ciceri* and the geographical distribution of the races. The search will continue to locate sources of multiple disease resistance for use in breeding.

Suitable nondestructive methods to evaluate and select single plants for nitrogen fixation will be developed, and efforts to evaluate *Rhizobium* strains for competitive ability will continue.

Tall types with yields similar to cultivars of conventional plant habit are now emerging; we will initiate crosses to improve seed size of that type and to incorporate double-podded and multiseeded characters and resistance to wilt and ascochyta blight.

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Contents

Physical Stresses 155
- Medium-Maturing Cultivars 155
- Postrainy-Season Crop 156

Biotic Stresses 156
- Diseases 156
  - Fusarium Wilt (*Fusarium udum*) 156
  - Sterility Mosaic 157
  - Phytophthora Blight (*Phytophthora drechsleri* f.sp. *cajani*) 158
  - Multiple Disease Resistance 160
  - Alternaria Blight (*Alternaria tenuissima*) 160
- Breeding for Resistance 161
  - Cooperation with AICPIP 162
  - Testing for Wilt Resistance in Kenya and Malawi 162
- Insect Pests 162
  - Surveys 162
  - *Heliothis armigera* 163
  - Podfly (*Melanagromyza obtusa*) 165
  - Nodule-Damaging Fly (*Rivellia angulata*) 166

Biological Nitrogen Fixation 166
- Leaf-Roll Symptoms 166
- Testing the Competitive Ability of *Rhizobium* Strains 166
- Nitrogen-Fixation Studies Using ^{15}N 167

Grain and Food Quality 169
- Cooking Quality 169
- Vegetable Pigeonpeas 170
- Protein and Amino Acids 171

Plant Improvement 171
- Early-Maturing Pigeonpeas 171
- Medium-Maturing Pigeonpeas 175
- Late-Maturing Pigeonpeas 175

Cooperative Activities 175
- International Trials 175
- All India Coordinated Trials 175
- Adaptation Yield Trials 177
- Distribution of Breeders' Material 177

Workshops, Conferences, and Seminars 177

Looking Ahead 179

Publications 179

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PIGEONPEA

The Pulses Improvement Program continued to develop genetic stocks, broad-based populations, lines, and cultivars of early-, medium-, and late-maturing pigeonpea, with a view to providing higher and more stable yields in the SAT. This report covers data collected in 1983, mostly from crops sown in 1982.

Our major activities were concentrated at 3 locations: (1) ICRISAT Center at Patancheru (18°N; 800 mm mean annual rainfall), where emphasis was on medium-maturing types for intercropping with major cereals in central and peninsular India; (2) Hissar (29° N; 450 mm rainfall), where early-maturing types were researched as sole crops with limited irrigation in pigeonpea-wheat rotations, a new cropping system of northwestern India; and (3) Gwalior (26° N; 900 mm rainfall), where emphasis was on late-maturing types for intercropping in the Indo-Gangetic plain.

Rainfall at all our test sites during 1982/83 was favorable for crop growth and above average yields were obtained from all locations. Attacks by pests and diseases were relatively light at Hissar and Gwalior, but pest damage was heavy in the pesticide-free areas at ICRISAT Center, permitting good differentiation in breeding for insect resistance. An increasing incidence of sterility mosaic disease was reported in many areas of northern and peninsular India.

Physical Stresses

Medium-Maturing Cultivars

Response to irrigation. In peninsular India, yields of adapted medium-maturing cultivars rarely exceed 2.5 t/ha, even under favorable conditions on experiment stations. To investigate the importance of stress from lack of moisture during the reproductive phase, we sowed three cultivars on an Alfisol and a Vertisol at the beginning of the rainy season. Results from three irrigation treatments (mid-October, mid-November, and mid-December) were compared with those from nonirrigated controls. Irrigation increased seed yield by 97% on the Alfisol and 19% on the Vertisol (Table 1), which suggests that for medium-maturing cultivars drought during the reproductive phase is a major yield-limiting factor on Alfisols. Even with irrigation, however, yields were considerably less than those obtained from early-maturing cultivars,

Table 1. Effect of irrigation during the reproductive phase on the first harvest yield (kg/ha) of 3 medium-maturing pigeonpea cultivars grown on an Alfisol and a Vertisol, ICRISAT Center, rainy season 1982.

	Vertisol				Alfisol			
Cultivar	Nonirrigated	Irrigated	Mean	SE	Nonirrigated	Irrigated	Mean	SE
BDN 1	1830	2090	1960		1040	2350	1690	
C 11	1900	2350	2120	±56	1140	2060	1600	±191
ICP 1-6	1620	1910	1760		870	1630	1250	
SE	±76				±238			
Mean	1780	2120			1020	2010		
SE	±41				±90			

The standard error for comparing cultivars with the same levels of irrigation on Vertisol is ±84, and on Alfisol, ±277.

suggesting that factors other than lack of moisture also limit yields of medium-maturing cultivars.

Effect of temperature on pod-set. One reason for the poor yields of medium-maturing cultivars at ICRISAT Center could be that their reproductive phase coincides with cool nights (temperatures as low as 8-10°C) that reduce or prevent pod-set. In a preliminary experiment using pigeonpea line ICPL 87, no pod set occurred at night temperatures below 7°C during the reproductive phase, but at 15°C pod-set was normal, which suggests that the critical night temperature for this cultivar is between 7 and 15°C. Further experiments are in progress to investigate effects of temperature in the range 7 to 15°C and to evaluate cultivar differences.

Postrainy-Season Crop

Our studies with pigeonpea sown at the beginning of the postrainy season have demonstrated the importance of high plant populations (ICRISAT Annual Report 1977/78, pp. 102-103), and of irrigation during that period (ICRISAT Annual Reports 1979/80, p. 107, and 1981, p. 137). This year we studied the interaction between plant population and irrigation with two medium-maturing cultivars, C 11 and AS 71-37. Sowings on 30 October 1982 were on flat beds in a split-plot design. The main plots consisted of an irrigated and a nonirrigated treatment, and the subplots a factorial arrangement of cultivars and plant densities. Three irrigations were given during the early vegetative, late vegetative, and reproductive phases of the crop.

Irrigation increased mean seed yields by 90% (800 to 1520 kg/ha), as seen in Figure 1, and total dry matter by 70% (1920 to 3260 kg/ha). This confirms our previous finding of a positive response to irrigation in postrainy-season pigeonpea. The lowest plant population, 25 plants/m², yielded significantly less seed and total dry matter than the other populations; it was suboptimal. Yields did not differ significantly among the other spacings, but 67 plants/m² gave the highest yields. No significant interactions were recorded between irrigation and plant populations for seed yield or total dry matter.

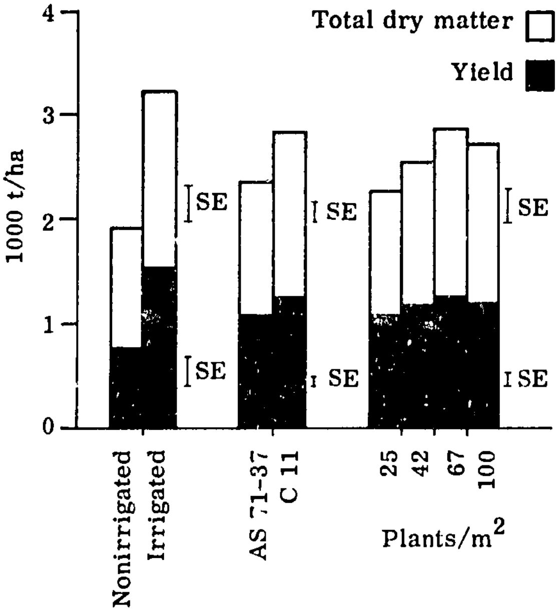


Figure 1. Yield and total dry-matter of two cultivars grown with and without irrigation at 4 plant populations, ICRISAT Center, postrainy season 1982/83.

Biotic Stresses

Diseases

Fusarium Wilt (*Fusarium udum*)

Screening for resistance. We continued to screen germplasm accessions, progenies, and advanced lines in wilt-sick plots at ICRISAT Center to identify wilt-resistant accessions and lines. Such screening is done in a wilt-sick plot where susceptible lines have more than 80% wilted plants. We select lines showing less than 20% wilt in the first screening and less than 10% subsequently. In early-maturing pigeonpea, 3 of the 8 lines with less than 20% wilt in 1981/82 had less than 10% wilt in 1982/83. Of an additional 412 early-maturing pigeonpea progenies or lines that we screened, 116 showed less than 20% wilt;

92 of 693 new germplasm accessions had some resistance. Seven (ICP 4784, 6654, 7806, 11308, 11324, 11368, and 11405) of the 468 accessions with less than 20% wilt in 1981/82 and 21 of 31 germplasm accessions screened for the 3rd year were wilt-resistant (less than 10% wilt) this year.

Of the 77 sterility mosaic-resistant accessions screened, 6 showed less than 20% wilt. Of the 52 progenies from wilt-resistant plants selected from sterility mosaic resistant accessions and lines during the two previous years, only 7 remained resistant to wilt. Of the 47 *Heliothis*-resistant accessions screened, 1 (PI 397668) remained free from wilt and 3 (ICP 8606 E1-3EB-W20, ICP 8583 E1-3EB-W20, and PPE 38-2-3EB-W20) had less than 10% wilt.

A large amount of breeding material—including F_4 to F_{10} progenies, F_4 bulks, early-, medium-, and late-maturity advanced materials, inbreds, converted male-sterile lines, elite breeding lines included in Medium-Maturity Pigeonpea Wilt-Resistant Lines Yield Trial (MPWRY) and Late-Maturity Pigeonpea Adaptation Yield Trial (LPAY), and vegetable types—was screened in the wilt-sick plot. Promising materials were advanced for further testing.

Table 2. Influence of crop rotation and intercropping on the incidence of pigeonpea wilt in a wilt-sick plot, ICRISAT Center, 4 cropping years.[1]

Line	Cropping year				Mean wilt at harvest (%)
	1979/80	80/81	81/82	82/83	
ICP 6997					
	P[2]	P	P	P	91 (74)[3]
	S	P	S	P	16 (23)
	P	S	P	P	62 (52)
	S	S	P	P	24 (29)
	S	S	S	P	15 (23)
	T	P	T	P	87 (71)
	F	P	F	P	31 (33)
	S/P	S/P	S/P	S/P	28 (32)
ICP 1		P	P	P	98 (82)
		S/P	S/P	S/P	20 (27)
SE					±(4.2)

1. A 4-year experiment with 8 treatments was started in 1979/80 with ICP 6997 as the susceptible line. In 1980/81, 2 more treatments were included with ICP 1 as the tolerant line.
2. P = pigeonpea; S = sorghum; T = tobacco; F = fallow; S/P = sorghum/pigeonpea intercrop.
3. Angular transformed values.

Influence of crop rotation and intercropping. This was the 4th year of this trial, which we started in 1978/79 in cooperation with ICRISAT agronomists. This year, pigeonpea ICP 6997 intercropped with sorghum had 28% wilt, in contrast to 91% in the sole crop; wilt incidence was 20% in contrast to 98% in pigeonpea ICP 1 (Table 2). Sorghum, planted every 3rd year as a break between pigeonpea crops, reduced pigeonpea wilt to 15% in the 4th year. Interestingly, a 1-year break in pigeonpea by sorghum or fallow reduced wilt to 16 or 31%, respectively. Both cotton and wilt-resistant pigeonpea (ICP 8863) were included in the 3rd year of the trial, but neither reduced wilt; maize intercropped with pigeonpea resulted in only a slight, nonsignificant reduction of wilt.

Those results were confirmed when we observed that 12 pigeonpea lines used by ICRISAT agronomists in sorghum/pigeonpea intercrop systems on an Alfisol had low wilt (5 to 24%, compared with 23 to 73% in sole crops of the same lines).

Influence of fertilizers. In collaboration with ICRISAT Farming Systems Research Program, we studied the influence of N, P_2O_5, K (each at 100 kg/ha), B, Mn, and Zn (50 kg/ha each of sodium borate, manganese sulphate, and zinc sulphate) on wilt incidence in the wilt-susceptible accession ICP 2376 in the wilt-sick plot at ICRISAT Center during the 1981/82 and 1982/83 seasons. High wilt incidence (95 to 98%) was not altered by fertilizer treatments.

Sterility Mosaic

Mite toxemia. This year we ruled out the role of mite (*Aceria cajani*) toxemia in causing sterility mosaic (SM) disease, as suspected in the literature, by: (a) establishing a healthy (pathogen-free) mite colony on BDN 1, a cultivar highly susceptible to SM; (b) maintaining this pathogen-free mite colony on BDN 1 without producing SM symptoms; and (c) establishing the pathogen-free mites as the vector of the SM pathogen.

Nature of the causal agent. Our efforts to determine the causal agent of SM continued, with several new extraction media and purification procedures in attempts to isolate the causal agent from infected pigeonpea. We consistently observed long, thin, flexuous, rod-shaped, virus-like particles, always in very low numbers. We also observed such virus-like particles in thin sections of *Scopolia sinensis* leaves affected by SM, but not in thin sections of infective eriophyid mites. Sap transmission of the causal agent was again unsuccessful.

Biology of the vector. As discussed, we raised a healthy (pathogen-free) colony of *A. cajani* on BDN 1, a highly susceptible pigeonpea cultivar, this year, and successfully maintained it without production of SM symptoms on BDN 1. We used mites from this colony to study pathogen-vector relations, and established that a single mite can transmit the pathogen; mites require a minimum of 5 min to acquire the pathogen and a minimum inoculation-access period of 30 min to transmit it.

Disease spread. We continued this study for the 3rd year, using an 'infector hedge' as the source of inoculum. Four rows of NP(WR)15, 75 cm apart and 100 m long, were sown on the west side, across the wind direction, of a 2-ha plot on 15 Dec 1981 and artificially inoculated by the leaf-stapling method.

Twenty-one, 100-m rows of BDN 1 were sown 17 June 1982 parallel to the infector row, downwind at 9.75 m intervals (after every 12 rows of test material) to serve as indicators for the disease. These 100-m rows of BDN 1 were divided into four sectors 25 m long, each represented by a square in Figure 2. Each square represents five, 4-m BDN 1 rows separated by 1-m alleys. Disease incidence (% diseased) was recorded at 1-month intervals from July to October.

The disease was observed in the last indicator row at 205 m within 30 days of sowing and decreased progressively with increasing distance from the source. Disease incidence progressively increased with time and reached 100% in the last indicator row by 20 January 1983 (approx 220 days after planting). The pattern of disease spread varied with prevailing wind direction; incidence was greater in the northwest side of the nursery in line with the southwest wind as shown in Figure 2. Further spread of the disease in the indicator rows also occurred along the wind direction, 55 and 71 days after sowing. The wind thus plays an important role in spreading the mite vector. Interestingly, while the disease spread downwind up to 2000 m from the inoculum source, it was found only up to 25 m upwind.

Screening for resistance. We screened a large amount of pigeonpea material including germplasm accessions, progenies, and advanced lines in the SM nursery, using the infector-hedge technique developed in 1981/82 (Figure 3).

We have screened 323 progenies selected from 143 germplasm accessions since 1976/77, and identified progenies of 124 accessions free from the disease. In this season, 89 of 470 new accessions, mostly belonging to the late-maturity group, were resistant. Since 1980/81 we have identified 24 progenies of 14 lines from *Heliothis*- and podfly-resistant lines, which also resist SM. We confirmed SM resistance in ICRISAT dwarf selection, ICPX 73081-16 D_3-30-B⊗-90-B⊗-B⊗.

Phytophthora Blight (*Phytophthora drechsleri* f.sp. *cajani*)

Screening for resistance. Because of the wider prevalence in India of the P3 than the P2 isolate of *P. drechsleri* f.sp. *cajani* reported last year, we used only the P3 isolate in our pot screening in the greenhouse at ICRISAT Center.

All the materials tested—4168 new accessions, 85 lines with promising resistance to *Heliothis*, 412 early-maturing lines from Hissar, 28 advanced lines, and 27 entries from Extra-Extra-Early Arhar (Pigeonpea) Coordinated Trial

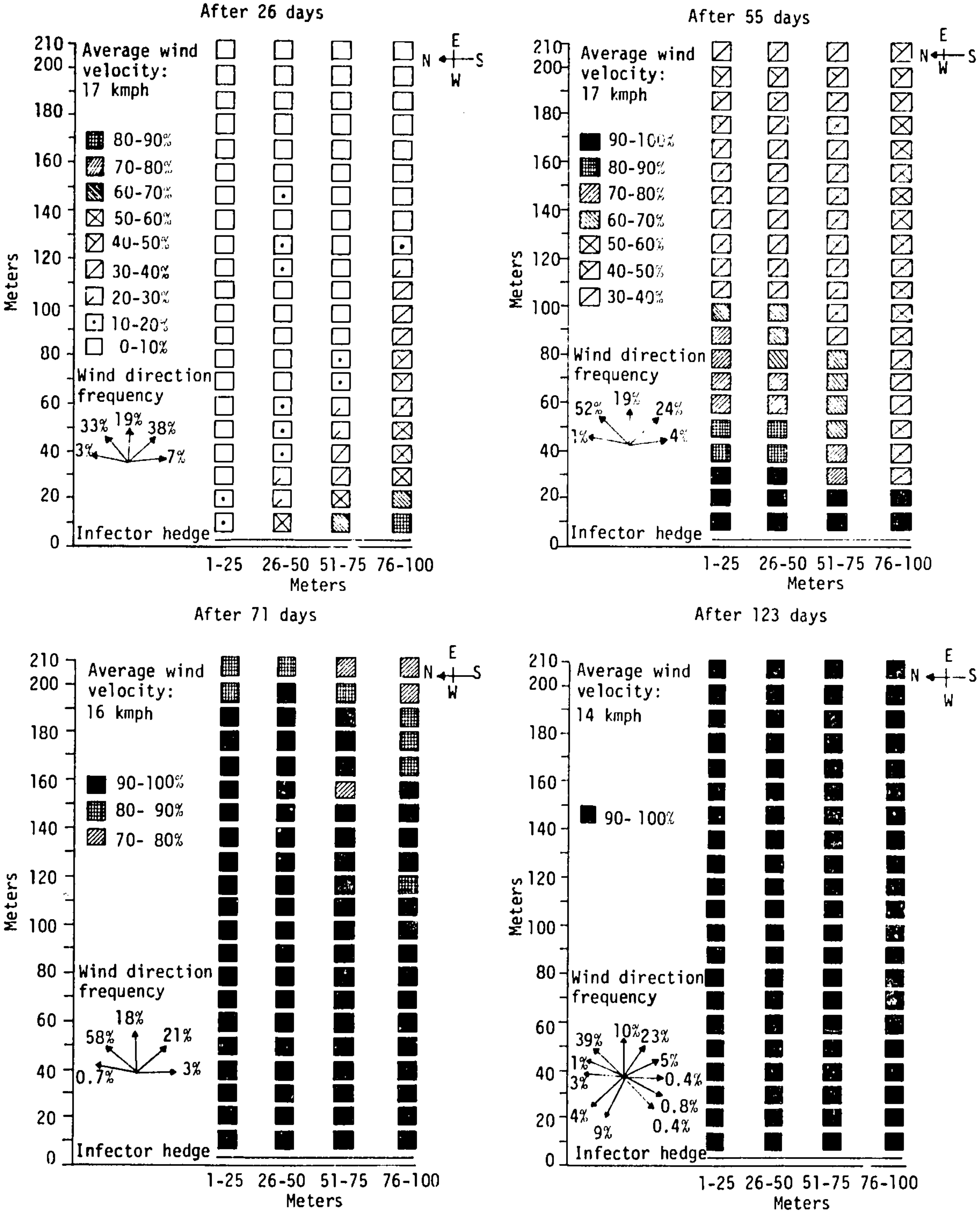


Figure 2. Showing extent and pattern of spread of sterility mosaic in BDN 1 indicator rows in the SMD nursery during rainy season 1982. Twenty-one, 100-m BDN 1 indicator rows were sown parallel to the infector-hedge every 9.75 m downwind. Disease incidence is indicated by different signs in the squares, each of which represents five, 4-m BDN 1 rows separated by 1-m alley. Arrows with figures indicate wind direction and frequency.

(EXACT), Extra-Early Arhar Coordinated Trial (EACT) and Early Arhar Coordinated Trial 1 (ACT-1)—were susceptible. Plants from material showing less than 50% blight were selfed for further testing.

Multiple Disease Resistance

We continued to screen breeding material in our multiple disease nursery for combined resistance to all three major diseases (wilt, SM, and phytophthora blight P2 isolate).

Of the 77 single plant selections of three lines (ICP 5097, 7194, and 8094) screened, 41 progenies from ICP 5097 and 12 from ICP 8094 had less than 20% wilt, SM, and blight; 34 of these progenies will be screened further. Of 199 single plant progenies screened from the cross ICPX 74360 and 4 from ICPX 74363, 141 had less than 20% wilt, SM, and phytophthora blight. The 9 progenies from cross ICPX 74360 and 2 from cross ICPX 74363 that remained free from infection by all three diseases will be screened further. Of the 64 progenies selected in the past from multiple-disease resistant lines, 18 that showed less than 20% incidence of the three diseases were selected for further screening. None of the 70 F_2 bulks from multiple-disease resistant crosses showed promising multiple resistance. Similarly, none of the 166 advanced lines screened had promising multiple resistance, although one line (ICPX 77125 VI ND2-4-2-B) showed resistance to SM and blight.

Alternaria Blight (*Alternaria tenuissima*)

We developed a simple-isolation, plant-propagator technique to screen pigeonpea material for resistance to alternaria blight and identified several sources of resistance (Figure 4). They included 7 elite lines from 4 centers in India, ICPL 6, 87, 146 (ICRISAT), MA 128-1,

Figure 3. We developed an infector-hedge technique for field screening of pigeonpeas for resistance to sterility mosaic disease at ICRISAT Center. The tall, thick pigeonpea growth at extreme left is the infector hedge. The medium tall, thick pigeonpeas parallel to the hedge, after every 12 test-entry rows, are the susceptible indicator rows of BDN 1. Thin population in test material beween indicator rows is because plants affected by sterility mosaic were removed.

128-2 (Banaras Hindu University, Varanasi), DA 2 (Dholi, Bihar), and 20(105) (Berhampore, West Bengal); two inbreds of ICP 7105; one advanced line from cross ICPX 74376; 17 multiple disease-resistant lines, one MPWRY entry (BWSMR 1); one Medium-Maturity Pigeonpea Sterility Mosaic Resistant Yield Trial (MPSRY) entry (IC 2376); and 9 *Atylosia* spp.

Breeding for Resistance

We screened populations from 38 crosses and 1325 advanced lines in the wilt-sick nursery, from 63 crosses and 764 advanced lines in the SM nursery, and from 70 crosses and 280 advanced lines in the multiple disease nursery.

Our past observations indicated that most sources of resistance to wilt, SM, and phytophthora blight yield less than existing released cultivars under normal field conditions, where there is a minimum of disease. Therefore, in collaboration with AICPIP, we initiated this year a special multilocational evaluation yield trial, under normal field conditions, of advanced lines, bulks of crosses involving adapted high-yielding cultivars, and cultivars with various sources of resistance to wilt and SM. All entries in the trial are also being tested in disease nurseries to confirm resistance.

Forty-two crosses were made in a line × tester mating design; 28 involved crosses between medium-maturing genotypes and sources resistant to SM, and 14 involved late-maturing genotypes and sources resistant to wilt and SM. Since sufficient hybrid seed was not available for testing, the crosses are being advanced to F_2 in 1983 for evaluation during 1984.

From 38 F_4 bulks grown in the wilt-sick nursery, 18 were selected for multilocational yield evaluations in the 1983 Medium-Maturity Pigeonpea Unselected Bulk (MPUB) trial. These crosses involve diverse parents with a wide range of plant characteristics, such as height, branching pattern, seed type, and proven resistance to wilt and SM.

Second and 3rd backcrosses to cultivars C 11 and BDN 1 were made to incorporate resistance to SM. Resistant plants resembling the recurrent parent were selected for crossing and progeny evaluation in 1983 in the disease nursery and in the observation nursery under normal field conditions. That material will be available for multilocational testing during 1984.

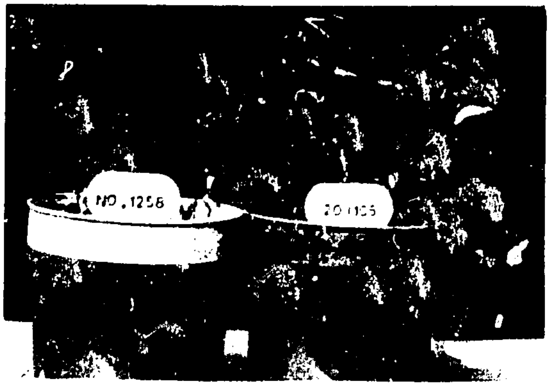


Figure 4. Alternaria blight is an important problem of postrainy-season pigeonpea in some parts of India. At right is a pigeonpea accession resistant to the blight, identified by screening in the isolation plant propagator. On the left is a susceptible line showing leaf blight and defoliation.

Of the early-maturing lines screened in the SM nursery, 102 were selected during 1983 for further evaluation, 6 for the Early Pigeonpea Sterility Mosaic Resistant Yield Trial (EPSRY) at Delhi, Pantnagar, and Hissar, 44 in the observation nursery at Hissar, and 52 in the SM nursery at ICRISAT Center.

Many medium-maturing genotypes resistant to wilt or SM were evaluated for agronomic acceptability at ICRISAT Center, including 79 wilt resistant lines in an unreplicated observation nursery, 35 in a SM advanced lines test, and 23 in a wilt resistant advanced lines test. Twenty-five of these lines outyielded the control C 11 and will be evaluated further in the advanced-lines, wilt-resistant test and in MPSRY.

In the MPSRY for 1982/83 ICPL 343, 345, 342, 341, and 346 yielded from 2090 to 2930 kg/ha, compared with 1920 kg/ha for the standard control C 11 (ICPL 131).

In a similar test in the MPWRY, 5 wilt resistant lines outyielded C 11 (Table 3). Three of them (ICPL 295, 337, and 338) were in fact derived from a C 11 population.

Four late-maturing advanced lines (ICPL 359, 365, 366, and 368) have been identified as resistant to alternaria blight. At Dholi, Bihar, where the disease is a serious problem, ICPL 365 yielded 3030 kg/ha, compared with 2720 kg/ha from the recommended cultivar Bahar, while ICPL 359 and 368 yielded 2620 and 2370 kg/ha, respectively.

Inheritance studies. We evaluated the parents and F_1, F_2, and backcross generations of several crosses in the wilt-sick plot at ICRISAT Center, but variable wilt reactions prevented clear interpretation of inherited resistance.

Two new diallel sets of 7 parents each—one involving various wilt resistant sources and the other SM resistant sources—were made to determine the genetic diversity of the sources of resistance and the allelic relationship of resistance genes. Line × tester crosses were also made to characterize the genetic relationship of the resistance of parents involved in these diallel sets for wilt (7 × 22) and SM (7 × 17).

Cooperation with AICPIP

We screened germplasm accessions, entries of the All India Arhar (Pigeonpea) Varietal trials, and breeding material from scientists of The All India Coordinated Pulses Improvement Project (AICPIP) for resistance to wilt and SM, and communicated the results to them.

ICAR-ICRISAT disease nurseries. The 5th ICAR-ICRISAT Uniform Trials of Pigeonpea for Wilt Resistance (IIUTPWR) and Sterility Mosaic Resistance (IIUTPSMR) were tested at 11 locations in India. This year we started two new nurseries in cooperation with AICPIP pathologists, one each for phytophthora blight resistance (IIUTPPBR) and alternaria blight resistance (IIUTPABR). The results of the four nurseries were presented separately in ICRISAT Pulse Pathology Progress Reports Nos. 26, 27, 31, and 32 (obtainable from the Pulses Improvement Program, ICRISAT).

Table 3. Characteristics of high-yielding, wilt-resistant pigeonpea lines tested in Medium-maturity Pigeonpea Wilt Resistant Yield Trial (MPWRY), ICRISAT Center, rainy season 1982.

ICPL No.	Days to 50% flowering	100-seed wt (g)	Yield (kg/ha)
295	119	10.1	3310
270	109	12.4	3200
337	122	11.0	3180
333	110	11.0	2960
338	122	10.7	2940
C 11 (control)	125	10.7	2880
SE	±0.9	±0.25	±246
Trial mean (n=18)	119	10.7	2670
CV (%)	1.5	4.6	18.4

Testing for Wilt Resistance in Kenya and Malawi

We sent pigeonpea lines resistant to wilt at ICRISAT Center for screening for wilt resistance again in Kenya and Malawi. Of the 28 lines tested in a wilt-sick plot at Katumani, Kenya, in 1981/82, 7 (ICP 9142, 9145, 9177, 10957, 11291, 11297, and MAU-E 175 sel.) were free from wilt. At Bvumbwe, Malawi, 31 lines were tested against wilt and root-knot nematode; 6 lines (ICP 8860, 8863, 9145, 10960, ICPL 270, and MAU-E 175 sel.) were free from both. ICP 9145 was free from wilt at both those locations in 1980/81.

Insect Pests

Surveys

The insect attacks on pigeonpea in 1982/83 were similar to those in most previous years. At ICRISAT Center and over much of southern India, the pod borer, *Heliothis armigera*, was the most damaging pest, particularly on medium-maturing cultivars flowering and podding in November and December. In many fields, all of the fruiting bodies from the first flush of flowering were destroyed by this pest. In some areas, the *Heliothis* populations persisted and destroyed the 2nd or compensatory flush of flowers, leaving little harvest for farmers. In central and northern India, *Heliothis* attacks were sporadic, but the podfly, *Melanagromyza obtusa*, was common and damaging in most areas. Other insects were only of localized importance this year.

Heliothis armigera

Pheromone traps. We made further progress in our cooperative research with a team from the Tropical Development Research Institute, UK, on use of the synthetic pheromones of *Heliothis armigera*. Our network of standard traps baited with the pheromones was extended to 118 traps across 58 locations in Bangladesh, India, Pakistan, and Sri Lanka (Fig 5). National entomologists record the number of male moths that enter the traps throughout the year and report the data to us. We expect the data to be valuable in quantifying variations of *Heliothis* populations across time and space, and to help determine factors that regulate such variations.

Our standard traps, which have white funnels, caught more than twice as many moths as traps incorporating funnels of any other color tested. That was surprising because moths are caught at night when color should be almost indistinguishable. Tests on the optimum height of traps showed it dependent on the height of surrounding crops. Greatest catches were from traps that were 1 m or less above the crop canopy. Inserting a slotted baffle around the pheromone dispenser greatly increased catches (5686 moths, compared with 1475 in the standard trap) in a 12-week test. The baffle has not been introduced into the traps in our network because we require data from standard traps, which are cheap and simple, over a lengthy period. However, if we were to embark on a mass trapping exercise to control this pest, the modifications would then be made.

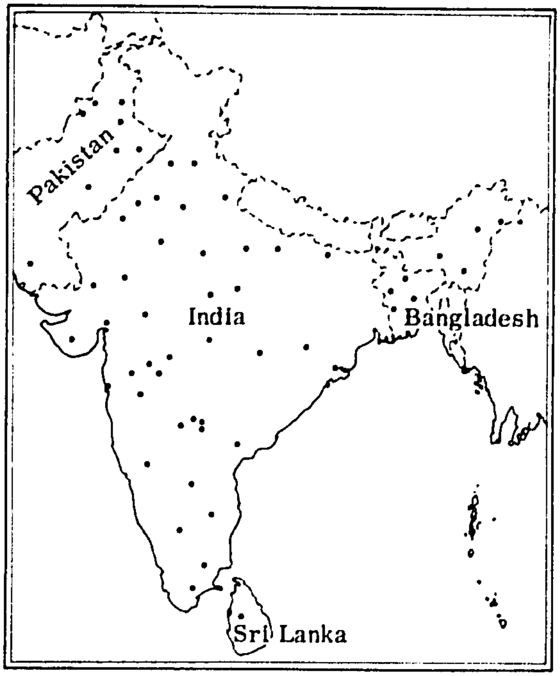


Figure 5. Locations of *Heliothis armigera* pheromone traps in the ICRISAT network covering Bangladesh, India, Pakistan, and Sri Lanka.

Interpreting pheromone-trap catch data continues to present problems. One example is shown in Figure 6 where the pheromone traps in a pigeonpea field adequately recorded moths resulting from the larval infestation, but gave no indication of moths that must have given rise to the infestation. That contrasted sharply from trap catches in sorghum, where the peak population of moths that gave rise to the infestation was clearly recorded.

Insecticide use. We continued comparisons of conventional hand-operated knapsack and motorized knapsack sprayers with controlled-droplet applicators (CDA), which use battery-powered spinning discs to produce a fine cloud of small (70 μ) droplets. In a trial in which pigeonpea was sprayed with endosulfan, we found again that the CDA gave at least as good *Heliothis* control as the conventional sprayers and had several obvious advantages, some of which are shown in Table 4. The spray mix applied by the CDA is more concentrated, however, so the sprayer operator has to be particularly well trained and protected to prevent toxic hazard.

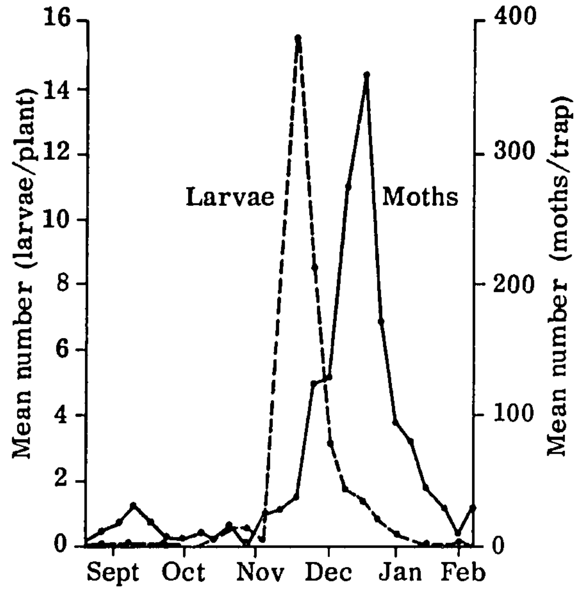


Figure 6. Numbers of *Heliothis armigera* larvae counted on plants and male moths caught in pheromone traps in a pigeonpea field, ICRISAT Center, 1982/83.

Host-plant resistance. Screening of germplasm and breeders' materials for resistance to *Heliothis* continued. The demonstration plots of our resistant selections were much less damaged this year than adjacent plots sown with commonly grown cultivars.

We are screening not only for nonpreference and antibiosis resistance, but also for tolerance to *Heliothis* and for compensatory ability. Selections with those different qualities were manifest in a trial of medium-maturing selections (Table 5) grown on a pesticide-free Vertisol at ICRISAT Center. In the trial pods from the first and second flushes of flowers were harvested separately. We confirmed resistance to *Heliothis* in lines ICP 7349, 1903, and 8229, which previously had been selected for this trait. The highest yield was obtained from ICP 3228, which had relatively severe borer damage, indicating its tolerance of borers. ICP 7941 and APAU 2208 gave more than half their yield in the second pick, thus indicating good compensatory ability or 'recovery resistance'. In marked contrast, ICP 8229 produced no yield from the second flush. The high coefficient of variation for yield in this trial may stem from variations in soils and pest attacks. In an adjacent trial containing the same entries, but protected by endosulfan, highest yields were from GS 1-3 and BDN 1, both potentially high yielding but pest susceptible.

In a trial conducted by our physiologists in which insect damage was simulated by damaging developing pods mechanically, APAU 2208 again showed exceptional ability to compensate for pod loss or damage.

Studies of the mechanisms of resistance are continuing in cooperation with the Max-Planck Institute, Federal Republic of Germany. From field and laboratory observations at ICRISAT Center, we have evidence that some of our selections, including ICP 1903, have nonpreference for oviposition by *Heliothis*. This selection and others appear also to have some antibiosis to the larvae. Work at the Max-Planck Institute has indicated that volatile chemicals are probably involved in the selection of pigeonpea for oviposition by *Heliothis* moths.

Breeding for resistance. We have increased our emphasis on breeding for insect resistance, having established that clear differences in resistance can be identified. Two of 28 F_4 lines from a

Table 4. Indicated characteristics of sprayers tested for pigeonpea protection, ICRISAT Center, 1982/83.

Sprayer characteristic	Hand-operated knapsack	Motorized knapsack	Controlled knapsack
Weight, empty (kg)	6.2	12.5	1.1
Weight, filled (kg)	21.5	25.0	1.6
Spray mix required (l/ha)	500.0	250.0	4.0
Time required for spraying (h/ha)	34.0	8.5	4.6

Table 5. The percentage of pods that were bored (mainly by *H.armigera*) and yields from the 1st and 2nd flushes of medium-maturing pigeonpea selections, ICRISAT Center, 1982/83.

Origion of selection	Pods bored (%)		Total seed yield (kg/ha)	Portion of yield from 2nd pick (%)
	1st pick	2nd pick		
ICP 3228	51	23	1620	38
ICP 7941	50	26	1250	56
ICP 7349	27	21	710	10
ICP 1691	53	29	1090	35
ICP 1903	29	18	1440	16
ICP 8229	20	–[1]	1100	0
ICP 5766	40	26	980	36
PPE 50-1	42	23	1230	33
APAU 2208	39	35	1580	53
AGR 20B	48	23	1210	39
GS 1-3	55	33	1070	32
BDN 1 (control)	48	23	1210	39
SE	±6.3	±2.7	±245	
CV (%)	26	19	35	

1. No pods available.

cross between ICP 1900-11 and BDN 1 produced pods under heavy *Heliothis* attack, where the insect removed virtually all pods from other lines. This appeared to be a case of nonpreference for egg laying by the adult moth on the resistant lines, as most lines flowered at about the same time. Those two lines have good agronomic appearance and will be tested for yield under sprayed and nonsprayed conditions, along with other identified resistant lines.

In addition we selected 289 F_2 plants with low borer attack and made 93 crosses: 15 each to study *Heliothis* and podfly resistance, 55 to combine sources of insect resistance, 6 to improve insect resistance of adapted cultivars, and 2 to combine *Heliothis* and wilt resistance.

Biological control. Experiments on the rearing and release of *Eucelatoria bryani*, a parasite imported from the USA for use against *Heliothis*, were continued at ICRISAT Center. Although we again recovered this parasite from *Heliothis* larvae in our pigeonpea fields immediately after its release, we found no subsequent generations. Scientists from India's Directorate of Plant Protection, however, have reported this parasite established in farmers' fields near Bangalore, where maximum temperatures are lower than at ICRISAT Center and where a wide range of host plants for *Heliothis* are available throughout the year.

Podfly (*Melanagromyza obtusa*)

Host-plant resistance. The podfly is particularly damaging on late-maturing pigeonpeas in central and northern India. Populations of this pest at ICRISAT Center are generally sufficient for field screening of the germplasm, but data from trials are often confounded by heavy *Heliothis* damage. This year, we tested some of the lines, which had been selected earlier for resistance or susceptibility at ICRISAT Center and at Gwalior, where the podfly is generally much more damaging than *Heliothis*. In one such trial, the three lines previously selected as resistant

Figure 7. This healthy scion of a normal pigeonpea plant developed leaf-roll symptoms when grafted on to a leaf-roll affected rootstock that had been inoculated with *Rhizobium* strain IHP 342.

had 18% pod damage by podfly, while, the three susceptible selections averaged 39% damage. Top yield in this trial was by ICP 8102-5, a podfly-resistant selection, which yielded 2620 kg/ha, 34% more than the 1950 kg/ha from NP(WR)15, the control.

The Nodule-Damaging Fly (*Rivellia angulata*)

Use of fishmeal. The larvae of this fly feed on nodules of pigeonpea and other legumes and can damage a large proportion of active nodules. We have been monitoring adult populations of this insect by using yellow sticky cylinders in our pigeonpea fields. We discovered this year that adding moistened fish meal to the cylinders tripled catches (from 80 to 264 ± 23.0 flies per cylinder per week). We also found that scattering fishmeal on the soil around pigeonpea seedlings led to substantial increases in nodule damage. This bait can be used to divert the flies from our microbiologists' trials where fly damage has been a regular problem.

Biological Nitrogen Fixation

Leaf-Roll Symptoms

Two *Rhizobium* strains IHP 324 and 342, isolated from Vertisol fields in 1979, induced leaf-roll symptoms on pigeonpea plants grown in Leonard jars (ICRISAT Annual Report 1979/80, p.118). In 1983, no nodules or symptoms were produced on *Trifolium subterraneum*, *Medicago sativa*, or *Glycine max* after inoculation with IHP 342. *Lathyrus sativus*, *Phaseolus vulgaris*, *Arachis hypogaea*, and *Macroptylium atropurpureum* (siratro) nodulated ineffectively, but leaf-roll symptoms appeared only on siratro.

A healthy scion of a normal pigeonpea plant grafted onto a leaf-roll-affected rootstock, which had been inoculated with *Rhizobium* IHP 342, developed leaf-roll symptoms (Fig.7). In the reciprocal graft no leaf-roll symptoms were seen, which suggests that leaf-roll symptoms result from an agent produced in the root nodules of plants inoculated with IHP 342, which is transported to the shoot.

Testing the Competitive Ability of *Rhizobium* Strains

The inoculation of field-grown pigeonpea with rhizobia has given inconsistent grain and total plant dry-matter responses (ICRISAT Annual Report 1978/79, p.107, 1979/80, p.119). We used the Enzyme-Linked Immunosorbent Assay (ELISA) technique this year to study the competitive ability of three strains (IHP 195, IHP 69, and F 4) in nodulating pigeonpea cultivars T 21 and ICP 1-6 under field conditions. *Rhizobium* cultures IHP 195 and F 4 were serologically related, though they were isolated at locations 1600 km apart. At sowing pigeonpea seeds inoculated with peat inoculants carried about 10 rhizobia/seed. The plants were well nodulated even in noninoculated plots, as the soil contained 4.6 × 10 pigeonpea rhizobia/g dry soil. The early-maturing pigeonpea cultivar T 21 yielded less grain (1080 kg/ha) than the medium-maturing cultivar ICP 1-6 (1860 kg/ha), and there was no response to inoculation in either nodulation or grain yield.

Twenty days after sowing, about 15% of the nodules formed by soil rhizobia on noninoculated T 21 reacted with the antisera (Table 6). Inoculation with IHP 195 increased the proportion of reactive nodules to 29% and with IHP 69 to 43%, while inoculation with F 4 had no significant effect. Thus strains IHP 195 and IHP 69 were more competitive than F 4. There were no significant differences in the proportion of nodules formed on ICP 1-6 by inoculant strains or between inoculated and noninoculated treatments. And at later stages of plant growth, neither cultivar showed significant differences between inoculated and noninoculated treatments or in percentages of nodules formed by inoculant strains. The inoculant strains we used were thus no more competitive than the native rhizobia. This stresses the need to continue efforts to obtain *Rhizobium* strains that are more effective and competitive than the native population.

Table 6. Percentages of nodules positive to antisera 20 days after planting with an ELISA technique that uses 3 *Rhizobium* strains, pigeonpea cultivars T 21 and ICP 1-6 grown on a Vertisol, ICRISAT Center, rainy season 1982.

Cultivar	*Rhizobium* strain	% nodules found positive Noninoculated	 Inoculated
T 21	IHP 195	16 (24)[1]	29 (33)
	IHP 69	16 (21)	43 (41)
	F 4	15 (23)	21 (27)
ICP 1-6	IHP 195	39 (38)	39 (38)
	IHP 69	22 (28)	35 (36)
	F 4	19 (26)	13 (21)

[1] Angular transformed values.

SE of difference of transformed means for comparing noninoculated vs inoculated with same cultivar and *Rhizobium* strain, ± 5.80.

Nitrogen-Fixation Studies Using ^{15}N

During the 1982 rainy season, we studied the possibility of using cement cylinders (75 cm dia, 60 cm deep) implanted in the field for nitrogen-fixation studies using ^{15}N. The bottom of each cylinder was closed with polyamide cloth, which prevents roots from penetrating but allows water to enter. The soil, excavated layer by layer, was used to fill the cylinders in the same sequence and a ^{15}N fertilizer-and-sucrose solution was applied on each 15-cm layer. The cylinders were conditioned for 15 days and then used for sowing. In this method crops grown in the cylinders had equal volumes of soil available to exploit during growth. Pigeonpea cultivar ICP 1-6, sorghum hybrid CSH 6, and sorghum cultivar IS 3003 were grown as sole and intercrops within the cylinders. Sorghum, IS 3003, a late-maturing cultivar with low nitrogenase activity, was used as the reference crop.

The treatments also included a sole crop of IS 3003 supplied with dried, fallen plant parts of pigeonpea (equivalent to about 40 kg N/ha) mixed with the topsoil at sowing.

At 38 days after sowing, pigeonpea plants from sole and intercropped plots were examined for nodulation, nitrogenase activity, and dry matter. No significant differences among the treatments were found for any factor (Table 7). The hybrid sorghum was harvested 112 days after sowing; the pigeonpea and sorghum cultivars, 160 days after sowing. Pigeonpea and sorghum grew better as sole crops than in intercrops. The isotope dilution method indicated that 88% of the nitrogen in the plant tops of pigeonpea grown as a sole crop was derived from biological nitrogen fixation (Table 8), which confirms results we obtained on a Vertisol field in the 1981 rainy season (ICRISAT Annual Report 1982, pp.146-147).

In the intercropped pigeonpea, the proportion of nitrogen derived from nitrogen fixation was 96%. Comparing sole and intercropped sorghum revealed no isotope dilution, suggesting that

Table 7. Nodulation, nitrogenase activity, and dry-matter production of 38-day-old pigeonpea plants grown sole and intercropped with sorghum in cylinders in Vertisol, ICRISAT Center, rainy season 1982.

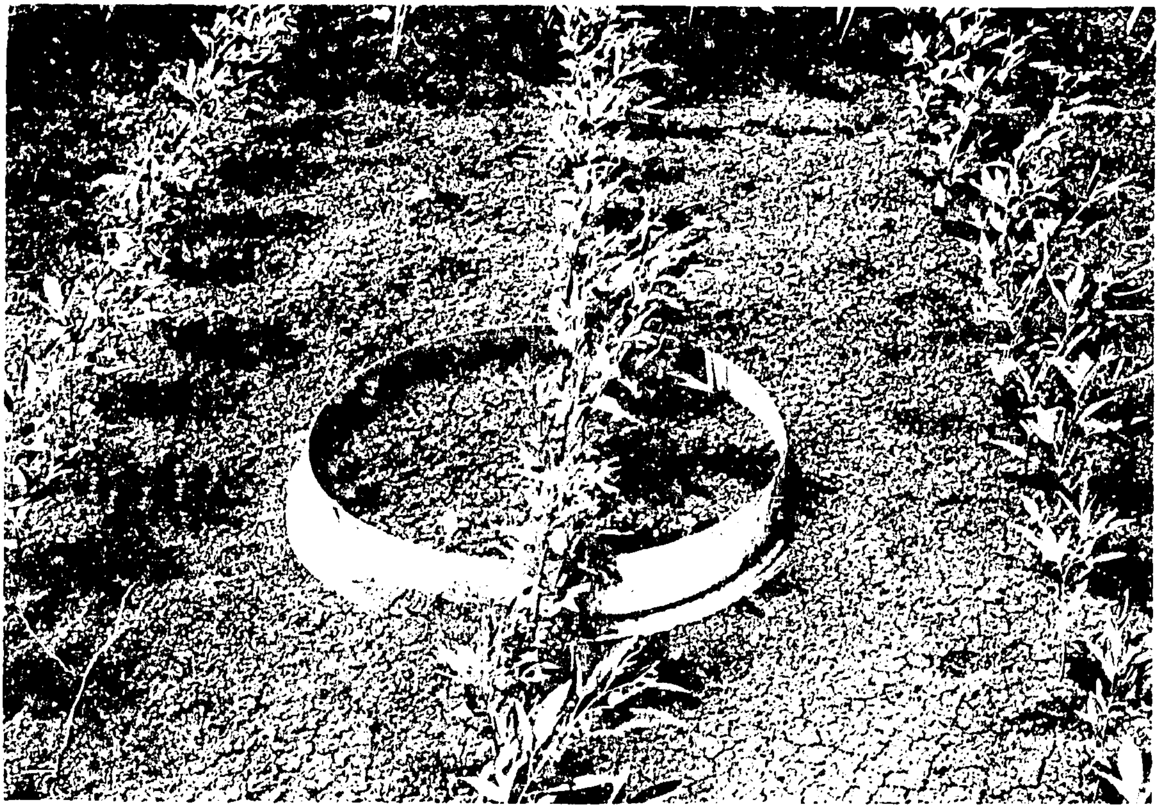
Treatment	Nodules/ plant (No.)	Damaged nodules/ plant (No.)	Nodules dry wt/ plant (mg)	Nitrogenase activity			Shoot dry wt/plant (g)	Total dry matter/ plant (g)
				μMC_2H_4/ plant (per hr)	μMC_2H_4/g dry nodule wt (per hr)	μMC_2H_4/ nodule (per hr)		
Pigeonpea-sole	49	5	117	18.5	158	0.38	2.38	2.82
Pigeonpea intercropped with sorghum hybrid CSH 6	58	16	108	14.8	139	0.26	2.03	2.37
Pigeonpea intercropped with sorghum cv IS 3003	53	9	125	17.9	144	0.33	2.02	2.39
SE	±5.3	±2.8	±17.3	±3.25	±13.0	±0.042	±0.184	0.22
CV (%)	22	62	33	42	20	29	19	20

Table 8. Grain and total dry-matter yields and N and ^{15}N uptake by pigeonpea ICP 1-6 and sorghum cultivars CSH 6 and IS 3003 at maturity, and nitrogen fixation by pigeonpea grown in cylinders, ICRISAT Center, rainy season 1982.

Treatment	Grain yield (g/cylinder)[1]	Total dry matter		Total N uptake		^{15}N atom excess (%)	% nitrogen derived from fixation by pigeonpea
		(g/crop per cylinder)	Total for each treatment	(g/crop per cylinder)	Total for each treatment		
1. Pigeonpea	PP 52.5	352	352	4.41	4.41	0.058±0.019	88.4
2. Sorghum hybrid CSH 6	SH 19.4	143	143	0.71	0.71	0.984±0.260	
3. Sorghum cv IS 3003	SC 4.7	252	252	0.84	0.84	0.498±0.179	
4. Pigeonpea intercropped with	PP 35.5	259	375	3.44	4.03	0.017±0.004	96.6
CSH 6	SH 18.6	116		0.59		1.032±0.245	
5. Pigeonpea intercropped with	PP 20.1	231	377	2.52	3.07	0.019±0.008	96.2
IS 3003	SC 0.3	146		0.55		0.796±0.084	
6. IS 3003 with fallen plant parts	SC 3.8	242	242	0.77	0.77	0.291±0.069	
SE	±3.8		±32.9		±0.312		

1. Area of cylinder-enclosed soil surface=0.44 m².

PP=Pigeonpea ; SH=Sorghum hybrid; SC=Sorghum cultivar.



Studying nitrogen fixation: 35-day old pigeonpea plants seen growing within and outside a cement cylinder filled with soil that had been labeled with ^{15}N fertilizer. A metal sheet helped raise the cylinder rim above ground level to prevent mixing of unlabeled soil from outside.

there was no transfer of biologically fixed nitrogen from pigeonpea to sorghum during crop growth. Comparing the sorghum cultivar grown with and without fallen plant parts of pigeonpea incorporated at sowing showed more dilution of ^{15}N with plant parts incorporated. Thus some mineralization did occur from the nitrogen available from the fallen plant parts, but it did not benefit the crop.

Grain and Food Quality

Cooking Quality

The cooking qualities of normal and ratoon harvests of 16 pigeonpea cultivars were investigated during the 1981/82 rainy season. Dhal samples of the cultivars were analyzed with the Instron food testing machine for cooking time, water absorption, solids dispersed, and texture. No large variation among cultivars was observed with regard to any characteristic. Cooking times of normal and ratooned samples showed no significant differences, indicating that ratooning has no adverse effect on cooking quality.

Pectin affects the water-absorbing capacity of some legume seeds. To test this, 20 pigeonpea lines, which differed in seed weight and color, were analyzed for pectic substances in seed coat and whole-seed samples. In no line was the amount of water absorbed by the seed during the soaking period related to the pectin content of either the seed coat or the whole seed. Water absorption did not correlate significantly with either seed size or seed color, and pectic concentration was not associated with seed color.

Sensory panel evaluating pigeonpea seeds in a grain and food quality test that supports ICRISAT plant improvement efforts.

Vegetable Pigeonpeas

Sugar content. To determine the variability of soluble sugars in green seeds, we collected samples of vegetable-type pigeonpea cultivars during 1982/83 from three locations (Hissar, Gwalior, and ICRISAT Center) and oven dried them before analysis. Soluble sugar contents ranged from 2.41 to 5.44% for 20 early-maturing lines from Hissar; from 3.62 to 8.54% for 18 medium-maturing lines from ICRISAT Center; and from 1.83 to 5.47% for 25 late-maturing lines from Gwalior.

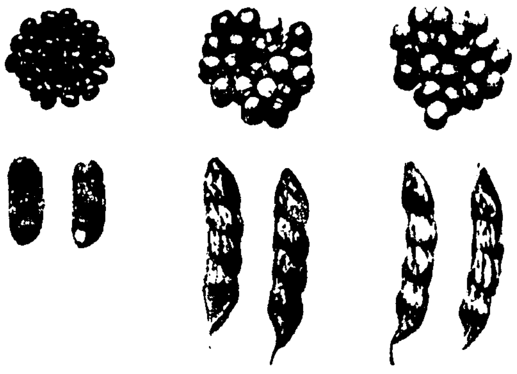
Ten vegetable-type pigeonpea lines—differing in seed color at the immature stage and originating from India, Kenya, Puerto Rico, Tanzania, and the University of West Indies—were grown in a trial at ICRISAT Center during rainy season 1982/83. Green seed samples were collected, freeze dried, and analyzed for soluble sugars (Table 9). ICP 7035, originating from India, contained the highest concentration of soluble sugars (8.5%), while ICP 6903 from Puerto Rico had the least (4.7%). Substantial variation in concentrations of glucose and fructose, and of sucrose was observed in these lines when they were estimated by thin layer chromatography.

Studies on the effect of drying methods indicated that oven drying (55°C) green seed samples reduced sugar values much more than freeze drying. Lower extractability of sugars in oven-dried samples may explain the difference.

We continued to study the organoleptic qualities of vegetable pigeonpeas. Cooked and uncooked samples of green seed from 16 cultivars differing in pod color were evaluated by a taste panel. Cooking significantly improved texture, flavor, and taste. Cultivar × cooking treatment interactions were not significant with respect to color, texture, flavor, or taste. This study confirmed our earlier findings that pod color did not influence organoleptic qualities of cooked green seed, and that overall acceptability

Table 9. The soluble sugars in vegetable pigeonpeas originating from indicated countries grown at ICRISAT Center, rainy season 1982.

				Immature		(% soluble sugar)	
Cultivar/line	Origin	Pod color	Seed color	Dry wt (mg/seed)	Soluble sugars (%)	Glucose± fructose	Sucrose
C 322	University of West Indies	Purple	Green	73.7	5.9	30.8	22.0
ICP 7035	India	Purple	Purple	79.8	8.5	22.9	35.6
ICP 9180	Kenya	Green/mix	Green	56.6	6.1	21.3	45.8
ICP 6903	Puerto Rico	Green/mix	Green	81.4	4.7	38.0	26.9
ICP 12074	Tanzania	Green	Green	63.4	6.3	22.3	43.8
Royce	University of West Indies	Greenish yellow	Green	62.3	6.5	29.2	53.9
SE				±9.26	±1.10	±5.92	±11.05



High protein lines with large seed: using the parent at left, *Atylosia scarabaeioides* (29% protein; 2.1 g/100 seeds), the pigeonpea line in the middle (29%; 11.9 g) was developed. At right is control cultivar C 11 (23%; 11.4 g).

of uncooked pigeonpeas was better from green pods than from purple pods.

Protein and Amino Acids

In wild relatives. Pigeonpea is generally recognized as deficient in the sulfur-containing amino acids, methionine and cystine. To determine whether any wild relatives of pigeonpea contain higher concentrations of those amino acids, so they might be used as sources in our breeding, we tested 85 accessions of 19 species of *Atylosia* and *Rhynchosia*. Defatted dhal samples from seed of the wild species were oxidized by performic acid and then analyzed for amino acids. Most species had higher concentrations of protein than pigeonpea, but not more methionine and cystine. Some accessions of *A. scarabaeoides* contained higher concentrations of the amino acids; they will be tested further.

In germplasm accessions. We continued screening pigeonpea germplasm accessions for methionine content, and analyzed defatted dhal samples of 636 accessions using the nitroprusside colorimetric procedure. Methionine concentrations of those samples ranged from 0.82 to 1.45 g/ 16g N and protein contents, from 18.0 to 28.3%.

Breeding for protein content. Several lines showing high protein concentrations in seed over 3 years were identified (Table 10). They were derived from crosses between adapted cultivars and wild relatives of pigeonpea *Atylosia scarabaeoides* and *A. albicans*, which have high seed protein. These lines had about 30% more protein than the control cultivar C 11. Agronomic evaluations of the lines are in progress. A correlation study of the progenies of 5 interspecific crosses indicated that seed size and protein level are essentially independent (r = -.30** to 0.28**). So it should be possible to develop high protein lines with large seed.

An F_1 diallel-cross analysis, involving three high and three low protein lines, indicated a preponderance of additive genetic variance and a significant maternal effect for protein content.

Plant Improvement

Early-Maturing Pigeonpeas

In peninsular India. Early-maturing pigeonpeas have shown excellent yield potential in northern India and in Queensland, Australia, but are not known to perform well in peninsular India. But in 1983 experiments their yield potential was greater in peninsular than in northern India.

Three cultivars, ICPL 4 (determinate), ICPL 87 (determinate), and ICPL 81 (indeterminate) were sown 15 June 1982 at four plant densities (16, 26, 42, and 67 plants/m^2) on an Alfisol at ICRISAT Center. Diammonium phosphate was applied at 100 kg/ha as a basal dressing. The plants were grown on 150-cm broadbeds, and irrigated through furrows between beds 2 July, 23 Aug, 15 Oct, 19 Nov, 14 Dec, and 21 Jan. The crop was sprayed with endosulfan when necessary to control *Heliothis*.

For ICPL 87 the first flush of pods was harvested by hand, while for ICPL 4 and 81 harvesting was by cutting the stems at 65 cm. At optimum spacing (different for each cultivar as indicated by significant genotype × spacing interactions), first harvest (September) yields were

Table 10. Protein level and seed size of promising pigeonpea lines grown at ICRISAT Center, 3 seasons.

	Protein %				
Cross line	1980/81 (F_5)[1]	1981/82 (F_6)[2]	1982/83 (F_7)[2]	Average increase over control (%)	100-seed weight (g)
T 21 × *A. scarabaeoides*					
515	25.5	29.3	29.5±0.06		11.1
C 11 bulk (control)	19.8	21.5	23.4	30.4	10.1
Baigani × *A. scarabaeoides*					
531	24.1	27.8	28.7±0.50		10.4
C 11 bulk (control)	19.9	21.1	22.4	27.0	10.5
566	26.3	29.0	30.4±0.38		9.0
C 11 bulk (control)	19.8	21.6	23.3	31.6	10.5
681	-	27.8	29.6±0.78		7.9
C 11 bulk (control)	-	20.8	22.1	35.7	10.6
684	24.0	28.3	29.9±0.76		6.9
C 11 bulk (control)	17.8	20.8	23.1	33.4	10.3
Pant A2 × *A. albicans*					
687	24.0	27.8	30.9±0.33		7.3
C 11 bulk (control)	17.8	20.8	22.3	35.5	10.6

1. Whole seed.
2. Seed coat removed.

F_5 and F_6 from single plants, F_7 from progeny rows.

2250 kg/ha for ICPL 4, 2690 kg/ha for ICPL 81 and 2380 kg/ha for ICPL 87.

Because of their perennial nature and favorable growing conditions, the cultivars produced a 2nd and then a 3rd flush of pods. ICPL 87 produced the highest 2nd and 3rd harvest yields, 2120 and 1000 kg/ha, respectively. Its total yield in 217 days from three harvests was 5500 kg/ha at a plant population of 16 plants/m^2— far superior to those from the best medium-maturing cultivars grown under high input conditions. So extra-early cultivars may have a large potential in peninsular India; experiments are in progress to determine how this potential can best be exploited.

In northwestern India. There is keen interest in using early-maturing pigeonpeas in rotation with wheat in northwestern India. At Hissar we continued to examine various cropping systems using early pigeonpea, which are increasing in importance in that area. We are trying to identify: genotypes that can be sown early March and April and intercropped with an early-maturing pulse crop such as mungbean (*Vigna radiata*); very-early-maturing genotypes to be harvested by mid-September to allow earlier planting of wheat; high-yielding genotypes maturing by mid-November, suitable in most areas for double cropping with wheat; and genotypes that can tolerate delayed planting, after a heavier-than-normal monsoon.

By sowing pigeonpea in late March or early April, intercropped with an early-maturing pulse, farmers hope, with irrigation, to get a full crop of the intercropped pulse and of pigeonpea and a good yield of firewood from the pigeonpea stalks. Although some pigeonpea starts flowering in less than 60 days when sown in late March or early April, and sometimes a few pods set before the high temperatures of May and June inhibit flowering and pod set, the main pod set

Table 11. Characteristics of promising pigeonpea lines (sown 30 April) intercropped with mungbean, Hissar, 1982.

				Yield (kg/ha)		
					Pigeonpea	
Entry	Days to flower[1]	100-seed wt (g)	Plant height (cm)	Mungbean grain	Grain	Dried stalk
ICPL 87	169	10.7	210	1330	2520	10560
ICPL 189	170	7.7	240	1260	2570	9170
ICPL 1	170	8.2	250	1140	2630	8890
ICPL 292	174	9.8	290	1250	2380	14690
ICPL 161	173	10.1	250	1330	2540	7780
T 21 (control)	178	7.8	280	1240	2370	10650
UPAS 120 (control)	168	7.2	240	1110	2140	6810
SE	±2.2	±0.15	±8.	±80	±94	±764
Trial mean (n=18)	167	9.0	245	1260	2290	9350
CV (%)	2.9	3.8	7.4	14.2	9.2	18.0

1. Days to 2nd flush of flowering. All lines flowered by late May or early June, but shed the flowers under high temperatures at that time. The 2nd flush after temperatures decreased produced the harvest.

Table 12. Performance of promising extra-early maturing pigeonpea lines, Hissar, rainy season 1982.

Entry	Days to flower	Days to mature	Plant ht (cm)	100-seed wt (g)	Grain yield (kg/ha)
ICPL 315	94	141	210	7.4	2540
ICPL 316	93	140	150	8.6	2460
ICPL 317	94	140	200	8.4	2430
Prabhat (control)	89	136	200	6.3	2100
SE	±1.4	±2.3	±9	±0.43	±116
Trial mean (n=20)	101	145	220	9.0	2480
CV (%)	2.0	2.3	5.7	6.7	6.6
ICPL 8302	70	126	150	7.7	3140
ICPL 8303	66	122	150	8.0	2780
ICPL 8304	71	125	160	8.2	2980
ICPL 313	70	127	170	7.8	2910
Prabhat (control)	72	126	200	6.3	2170
SE	±0.9	±1.7	±6	±0.29	±97
Trial mean (n = 24)	70	124	160	8.0	2600
CV (%)	1.8	2.0	5.2	5.1	5.3

Table 13. Characteristics of promising early-maturing pigeonpea lines grown at Hissar, rainy season 1982.

Entry	Days to flower	Days to mature	Plant ht (cm)	100-seed wt (g)	Grain yield (kg/ha)
ICPL 186	105	153	266	9.8	4000
UPAS 120 (control)	105	146	260	7.2	2740
SE	±1.3	±2.2	±1.7	±0.20	±103
Trial mean (n = 18)	106	151	247	9.2	2590
CV (%)	1.8	2.0	7.2	3.0	5.6
ICPL 8309	87	149	215	11.4	2960
ICPL 8310	95	148	237	10.5	3270
ICPL 1 (control)	107	146	236	8.0	2820
SE	±1.1	±1.7	±9.3	±0.24	±129
Trial mean (n = 30)	96	151	220	10.0	2350
CV (%)	1.9	1.9	7.3	4.1	9.5
ICPL 289	95	146	217	10.8	2980
ICPL 8311	94	146	236	11.3	3100
ICPL 1 (control)	106	150	278	7.8	2940
SE	±1.3	±1.7	±7.3	±0.20	±164
Trial mean (n = 49)	99	149	242	9.0	2400
CV (%)	2.3	1.9	5.2	3.8	11.8
ICPL 8312	66	130	174	8.5	2550
ICPL 8313	75	132	213	11.0	2780
UPAS 1320 (control)	96	133	261	7.2	2480
SE	±1.1	±2.2	±6.5	±0.20	±124
Trial mean (n = 24)	69	127	177	7.8	2390
CV (%)	2.1	2.4	5.2	3.6	7.3

comes after temperatures drop in July (Table 11). This results in tall vegetative growth that may produce more firewood, but can make spraying difficult. Shorter genotypes would be easier to spray, but they should not drastically reduce stalk yields. For that reason ICPL 87's high yield and short stature may give it advantages (Table 11).

Extra-early-maturing lines, which allow farmers to sow wheat early, have again performed well at Hissar. Two lines, ICPL 313 and 316, which performed well last year (ICRISAT Annual Report 1982, p.158) again produced good yields, but others were even better (Table 12).

Outstanding yields were obtained at Hissar from lines sown mid-June and maturing by mid-November (Table 13). In addition all these lines have good seed size. They mature early enough in most areas for farmers to prepare the fields and sow wheat after harvesting the pigeonpea.

Delayed sowing of pigeonpea may be unavoidable, so genotypes suitable for such a situation should be identified. Delayed sowing also reduces plant height, which makes spraying and other management practices easier. With a high seed rate (ICRISAT Annual Report 1982, p.153) good yields can be obtained in a short period after delayed sowing (Table 14).

Table 14. Performance of some promising early-maturing pigeonpea lines with delayed sowing (26 July), Hissar, 1982.

Entries	Days to flower	Days to mature	100-seed weight (g)	Plant height (cm)	Yield (kg/ha)
ICPL 155	69	119	8.1	120	3090
ICPL 151	66	105	10.9	110	3050
ICPL 81	68	111	7.4	110	3020
ICPL 161	79	123	9.1	100	2920
ICPL 1	69	112	8.0	110	2870
ICPL 312	66	104	11.4	90	2810
SE	±0.2	±1.0	±0.15	±7	±90
Trial mean (n = 12)	66	108	8.5	100	2570
CV (%)	0.6	1.6	3.1	12.1	6.1

Medium-Maturing Pigeonpeas

At ICRISAT Center our major breeding activity continued to be with medium-maturing pigeonpeas. Growing conditions were good this year; yields were above normal. As part of the activity, we made 364 crosses, grew out more than 5000 single plant selections and 1060 bulks and bulk populations, and tested 1100 advanced lines for yield. Work on this maturity group continued also to emphasize development of lines that resist various pests, diseases, and biotic factors that reduce yield. Details appear elsewhere in this report.

Late-Maturing Pigeonpeas

We continued to breed late-maturing pigeonpeas at Gwalior where, unlike the previous 3 years, crop growth was excellent this year in all experiments. We also conducted trials of advanced lines this year at the Morena Centre of Jawaharlal Nehru Krishi Vishwa Vidyalaya, 35 km north of Gwalior. Mean yield at Gwalior was 2.6 t/ha; at Morena 2.5 t/ha. Yields of several advanced lines exceeded 3 t/ha (Table 15).

Cooperative Activities

International Trials

During 1983 the Pigeonpea Observation Nursery (PON) continued to be the most popular nursery with pigeonpea workers outside India. We supplied 30 of these nurseries to 22 workers in 15 countries. The wide range of material in the PON allows researchers to determine the type of material most likely to be adapted to their growing conditions. In addition we supplied 17 Pigeonpea Adaptation Yield (PAY) Trials containing elite lines of early- (EPAY), medium- (MPAY), and late-maturing (LPAY) lines to 6 countries other than India. We also assembled a set of vegetable-type lines, which we sent to 7 Caribbean countries.

All India Coordinated Trials

We continued to cooperate with AICPIP. More than one quarter of the entries in the Arhar Coordinated Trials (ACT) of AICPIP were submitted by ICRISAT with two in the extra-extra-early trial (EXACT), six in the extra-early trial (EACT), three in the early-maturing trial (ACT-1) five in the medium-maturing trial (ACT-2), and two in the late-maturing trial (ACT-3).

Two lines, ICPL 1 and ICPL 6, were accepted by the Indian Central Sub-Committee on the Release of Varieties as pure seed sources for the two cultivars, UPAS 120 and T 21, respectively. Each one represents the best performing line of a series developed from single plant selections from each cultivar as part of our variety purification program. They were identified after 3 years of testing in AICPIP trials throughout India (Table 16).

Lines that performed well in the EACT compared with control cultivar UPAS 120 were: ICPL 81, which matured earlier, ICPL 87, which yielded well in the peninsular and central zones; ICPL 151, with large seed; and ICPL 161, which performed well at some locations. In the early-maturing ACT 1, the 2nd-year entry, ICPL 189, outyielded the control, T 21, an average of 10% over 8 locations (1610 compared with 1470 kg/ha), had larger seed (8.3 compared with 7.8 g/100 seeds for T 21), and matured only 2 days later.

In ACT 2 hybrid ICPH 2 continued to perform well (Table 17; see also ICRISAT Annual Reports, 1981, p.147; and 1982, p.162). Although this is the most widely tested pigeon-

Table 15. Performance of top-yielding pigeonpea lines in yield tests of late-maturing advanced lines at ICRISAT research stations, Gwalior and Morena, rainy season 1982.

Entry	Days to flower	Days to mature	100-seed wt (g)	Yield (kg/ha)		
				Gwalior	Morena	Mean
ICPL 8397	154	271	9.9	3170(1)[1]	3440(2)	3305
ICPL 8398	151	275	9.0	2880(3)	3710(1)	3300
ICPL 83132	152	273	7.9	3010(2)	3300(3)	3160
GW-3 (control)	148	272	8.5	2810(7)	2890(4)	2850
SE	±2.9	±0.9	±0.30	±247	±191	-
Trial mean (n = 22)	148	272	8.8	2530	2470	2500
CV (%)	3.9	0.7	7.1	20.0	15.0	
ICPL 8364	137	252	9.6	3260		
ICPL 8365	141	254	8.1	2810		
GW-3 (control)	131	251	8.0	2510		
SE	±3.1	±1.1	±0.27	±184		
Trial mean (n = 20)	143	254	9.4	2370		
CV (%)	4.3	0.9	5.7	15.5		
ICPL 8377	154	267	7.3	3670		
ICPL 8378	152	270	6.7	3660		
ICPL 8379	147	263	7.4	3590		
ICPL 8380	149	264	7.3	3520		
ICPL 8381	151	267	7.0	3500		
ICPL 8382	152	267	7.0	3420		
GW-3 (control)	150	263	7.7	3040		
SE	±2.6	±2.2	±0.3	±256		
Trial mean (n = 18)	150	266	7.1	3070		
CV (%)	3.0	1.4	7.4	14.5		

[1] Figures in parentheses represent overall rank in trial.

pea hybrid in the world, it is being tested for another year in ACT 2 and in on-farm tests in the Indian national minikit trials and in various agronomic trials throughout India. Based on this year's results, hybrids ICPH 6 and 7, which also performed well, generally are less promising. Our wilt-resistant line ICPL 270 performed better this year than last year (ICRISAT Annual Report 1982, p.162).

Table 16. Mean performance of ICPL 1 and ICPL 6 and original pigeonpea cultivars UPAS 120 and T 21 at several locations in the AICPIP trials over a 3-year period (1980-1983).

Cultivar	Days to mature	100-seed wt (g)	Grain yield (kg/ha)
No. of comparisons	26	19	29
ICPL 1	131	7.4	1820
UPAS 120	127	6.6	1790
No. of comparisons	34	21	23
ICPL 6	144	8.0	1580
T 21	142	7.8	1580

Adaptation Yield Trials

We again made available to breeders in India our most advanced breeding lines in several Pigeonpea Adaptation Yield (PAY) trials. We had 18 entries in EPAY and received results from 10 locations; ICPL 155 produced the highest yield while ICPL 94 was the best extra-early-maturing line, yielding over 22% more than the control cultivar Prabhat (2100 kg/ha vs 1720 kg/ha), while maturing 2 days later. In addition, it was much shorter with larger seed. In the MPAY, grown at 9 locations, ICPL 265 was the highest yielding of 24 entries; ICPL 276, 281, and 306 also performed well, and are being retested.

Distribution of Breeders' Material

In addition to our entries in the AICPIP trials and in the adaptation yield trials, we supplied about 770 breeding lines to 71 scientists in India. Outside of India, in addition to the trials mentioned earlier, we supplied 682 breeding lines to 44 research workers in 31 countries. That material included F_1 hybrids, unselected F_1 to F_7 populations, disease-resistant lines, male-sterile stocks, and advanced lines.

Workshops, Conferences, and Seminars

Consultative Group Meeting for Asian Regional Research on Grain Legumes

Forty-eight participants representing research organizations in India, Indonesia, Japan, Malaysia, Nepal, Pakistan, Philippines, Thailand, ICRISAT and other international organizations with responsibilities for agricultural development in Asia met 11-15 December, at ICRISAT Center, to discuss ways that ICRISAT can help improve groundnut, chickpea, and pigeonpea production in the region, because production has fallen well below demand.

The group agreed that a coordinated regional approach to research would be productive, and that an operational network of scientists and policymakers should be established. Particular attention should be paid to crop improvement and related cropping systems and socioeconomic research. Improvements are also needed in transfer of germplasm between research centers, training research staff, and exchange of information and advice, particularly among visiting specialists. The group's recommendations and executive summaries of the papers presented are available from Information Services, ICRISAT.

Group Discussion on Pulse Pest Management

Twenty-five pulse entomologists from India, Jordan, Pakistan, Thailand, USA, ICARDA, and ICRISAT assembled at ICRISAT Center, 5-10 December, to share their experience and to plan for future research and development of pest management on chickpea and pigeonpea. The discussions focused on host plant resistance, sur-

Table 17. Performance of ICRISAT pigeonpea entries in the AICPIP ACT-2 trial grown in peninsular India, rainy season 1982.

				Yield (kg/ha)								
Entries	Years tested (No.)	Days to mature[1]	100-seed wt (g)[2]	Akola 18[3]	Jalna 20	Badnapur 20	Parbhani 16	Madhira 13	ICRISAT Center 19	Bangalore 16	Gulbarga 18	Mean
Hybrids												
ICPH 2	3	167	8.6	980(2)[4]	1750(2)	840(3)	1380(4)	1910(6)	1880(10)	1320(2)	1000(11)	1380
ICPH 6	2	171	8.8	760(5)	1780(8)	730(7)	1380(4)	1490(12)	1930(9)	1310(3)	890(12)	1280
ICPH 7	1	168	8.4	1030(1)	2110(1)	780(4)	1130(11)	1630(9)	1700(16)	1160(6)	660(17)	1280
Lines												
ICPL 270	2	173	11.5	480(14)	1830(5)	730(8)	620(16)	2200(1)	2210(1)	860(14)	1680(2)	1330
ICPL 304	1	170	10.2	660(9)	1920(3)	880(2)	1170(10)	1670(8)	1820(12)	1080(7)	1080(9)	1290
Controls												
C 11		173	10.0	740(6)	1750(13)	650(11)	1210(8)	1730(7)	2050(5)	920(11)	1380(9)	1300
BDN 1		163	10.3	640(11)	1700(14)	1000(1)	840(15)	1620(10)	2140(2)	830(15)	1490(4)	1280
SE				±83	-[5]	±60	-	±180	±92	±106	±152	
Location Mean				680	1710	670	1200	1770	1870	1040	1110	1260
CV (%)				27	-	18	-	16	12	20	23	

1. Mean of 9 locations.
2. Mean of 8 locations.
3. No of entries in trial.
4. Figures in parentheses represent overall rank in trial.
5. - = not available.

vey and surveillance, insecticide use, biological and cultural control, and the investigation of pest management and its adoption. Participants indicated the following requirements for work in India: standard methodology for surveillance and in selecting for host plant resistance; an illustrated handbook for pest recognition; and determined efforts to use available natural control elements. It was agreed that an operational research project concerning village-level pulse pest management or management of a large area has high priority.

Pigeonpea Breeders' Meet

Over 30 scientists from India, one from Puerto Rico, one from Malawi, and one from New Zealand attended the meet, 5-7 December, at ICRISAT Center. Several special topics were discussed, breeding material was selected by the participants, and it was agreed that a special early-maturing, high-input trial will be grown at several locations in peninsular India.

Looking Ahead

The nutrient and water requirements of extra-early pigeonpeas will be investigated and the feasibility of the high-input system will be tested further. We will intensify efforts to breed pigeonpeas suited to the high-input cropping system and will select early-maturing types for single harvest and other types for multiple harvests.

Experiments on crop recovery from simulated insect pest attack will continue. Studies of competition in intercrops will be added. In collaboration with agroclimatologists, we hope to study drought tolerance of pigeonpeas.

Our search will continue for resistance to the P3 isolate of the phytophthora blight fungus and multiple resistance to pigeonpea's three major diseases, wilt, sterility mosaic, and phytophthora blight. We are particularly interested in establishing the nature of the pathogen that causes SM and its races in India. Studies of the race situation in *Fusarium udum* in India and Africa will be intensified. Work on nematodes, particularly the cyst nematode, will be initiated.

It should be possible to select plants with higher resistance to insect pests from crosses already made, and to test them at several locations in the near future.

We will continue efforts to identify *Rhizobium* strains that are more effective and more competitive than the native soil rhizobia. We aim to purify the lines selected for greater nodulation and nitrogen fixation for use in breeding programs.

We will expand our cooperative efforts with national programs outside India, particularly in Southeast Asia, as a result of the 1983 Consultative Group Meeting for Asian Regional Research at ICRISAT.

Publications

Institute Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), **Pulse Improvement Program.** 1983. International Pigeonpea Newsletter no.2 (Faris, D.G., ed.). Patancheru, A.P. 502324, India: ICRISAT.

van der Maesen, L.J.G. 1983. World distribution of pigeonpea. Information Bulletin no.14. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.

Journal Articles

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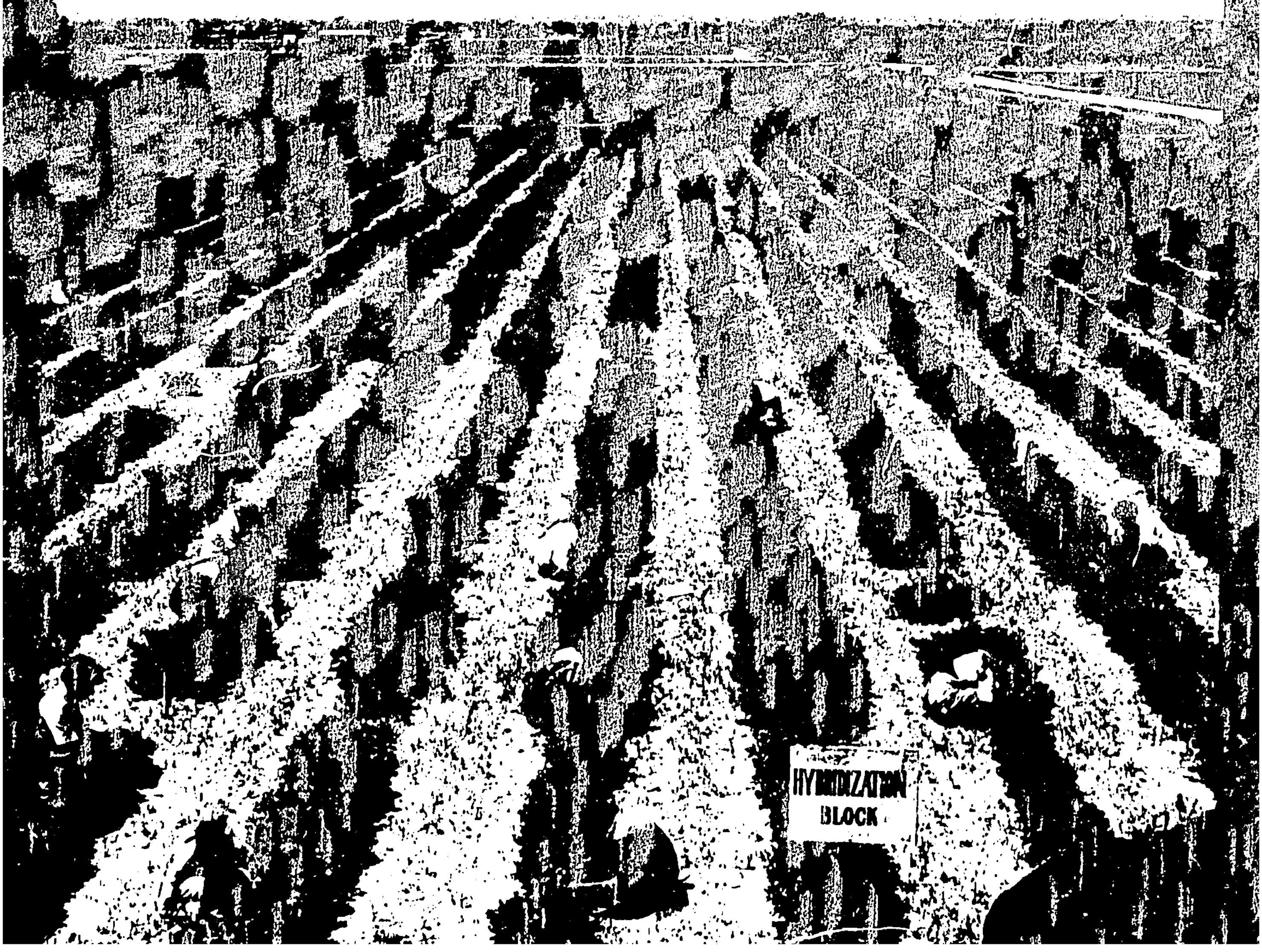
GROUNDNUT



Contents

Physical Stresses 183
  Drought 183
    Screening and Physiology 183
    Gypsum and Drought Interactions 184

Biotic Stresses 184
  Diseases 184
  Foliar Fungal Diseases 186
  Soilborne Fungal Diseases 192
    Pod Rot 192
    The Aflatoxin Problem 193
  Virus Diseases 195
    Bud Necrosis 195
    Peanut Clump 197
    Peanut Mottle 199
    Mild Mosaic 200
  Insect Pests 200
    Incidence at ICRISAT Center 200
    Losses from Insects at ICRISAT Center 200
    Cultural Practices for Pest Management 201
    Controlling *Lachnosterna fisca* and *Spodoptera litura* with Insecticides 201
    Host-Plant Resistance 201
    Breeding for Pest Resistance 203

Nitrogen Fixation 205
  Response to *Rhizobium* Inoculation 205
  Nitrogen Fertilizer Studies 207

Plant Improvement 207
  Breeding for High Yield and Quality 207
    Postrainy Season 1982/83 207
    Rainy season 1983 209
  Photoperiod Adaptation 209
  Earliness and Dormancy 210
  Using Wild Species 212
  Producing Interspecific Derivatives 213
  Material Supplied to Breeders 214
  Barriers to Hybridization 215
  Ovule and Embryo Culture 215

International Cooperation 216
  Cooperation with AICORPO 216
    Coordinated Yield Trials 216
    Multilocation Trials 216
  Regional Program for Southern Africa 219

Workshops, Conferences, and Seminars 225

Looking Ahead 227

Publications 228

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GROUNDNUT

Seventy percent of the world's groundnuts are produced in the semi-arid tropics (SAT), more than any other legume. Containing approximately 25% protein and 50% edible oil, groundnuts are important to SAT farmers as food and for cash. The haulms remaining after the pods are removed are a valuable, nutritious animal feed. The average yield of groundnut for the SAT remains extremely low (around 800 kg/ha dried pods) and yields fluctuate widely from unreliable rainfall. Disease and insect pest attacks also severely reduce yields.

During the 1982/83 postrainy and 1983 rainy seasons, we continued research into disease and insect pest problems and drought and nutrient stresses. We also studied interactions between the various stress factors. Considerable effort went into developing high-yielding cultivars, particularly under stress-free situations. Our continuing improvement strategy is to use the genetic diversity in groundnut and its wild relatives to breed for stable resistance or tolerance to the major yield reducers.

Physical Stresses

Drought

Screening and Physiology

During the 1982/83 postrainy season, drought screening was conducted on 484 genotypes; 164 of these are being retested to confirm their attributes.

Trials conducted at Anantapur in the 1982 rainy season on material selected from last year's drought screening experiments showed that some material significantly outyielded local varieties. NC Ac 17090 produced 1.15 t/ha compared with 0.5 t/ha by Robut 33-1 (with 22 cm of rain during the crop life). Cultivars varied widely in total dry matter accumulated and in proportions of dry matter used for pod growth (Fig. 1), which increases our confidence in ICRISAT's drought screening methods.

In another experiment under line source irrigation 25 lines were subjected to 12 patterns of drought stress with 8 intensities within each pattern. The drought patterns varied time and duration of stress in single and multiple combinations as detailed in Table 1. Regression analysis of pod yield on applied water during the stress phase allowed comparison of drought effects on individual cultivars or on the overall response of groundnuts (represented by this sample) in 96 environments that varied principally in available water.

Mean responses of each of the 25 groundnut cultivars to the drought stress patterns were obtained by regressing total biomass or pod yields (Fig. 2) on the cumulative water applied

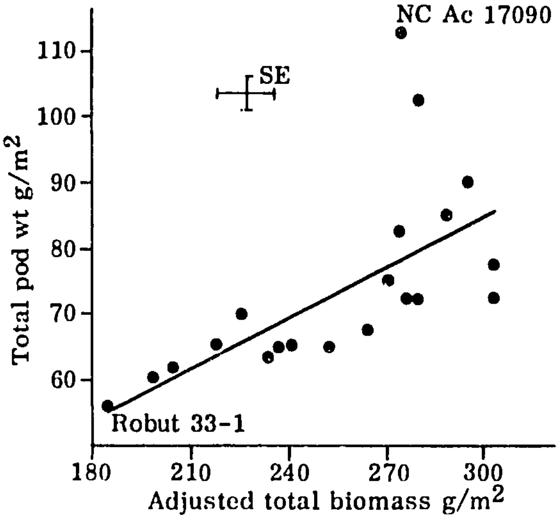


Figure 1. Relationship between total pod weight and adjusted total biomass in 20 selected groundnut genotypes (highest and lowest 2 identified), Anantapur, rainy season 1982.

Table 1. Timing and duration of irrigation treatments applied in an experiment to determine effects of drought patterns on crop response in groundnuts, ICRISAT Center, postrainy season 1982/83.

DAS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
0	U	U	U	U	U	U	U	U	U	U	U	U
15	U	U	U	U	U	U	U	U	U	U	U	U
29	LS	LS	U	LS	LS	U	LS	U	U	U	LS	U
39	LS	LS	U	LS	LS	U	LS	U	U	U	LS	U
51	LS	LS	U	LS	LS	U	LS	U	U	U	LS	U
57	U	U	LS	U	LS	U	LS	LS	U	U	U	U
66	LS	U	LS	U	LS	U	LS	LS	U	U	LS	LS
72	LS	U	LS	U	LS	U	LS	LS	U	U	LS	LS
82	LS	U	U	LS	U	LS	LS	U	U	U	LS	LS
93	U	U	U	LS	U	LS	LS	U	LS	LS	U	U
100	LS	U	U	LS	U	LS	LS	U	LS	LS	U	LS
111	LS	U	LS	U	U	LS	LS	U	LS	LS	U	LS
118	LS	U	LS	U	U	LS	LS	U	LS	U	U	LS
129	U	U	U	U	U	U	U	U	U	U	U	U

DAS = Days after sowing; U = Uniform irrigation;
P = Drought pattern; LS = Line source irrigation.

during each pattern. The results demonstrated that early stress (P2) did not influence pod yields greatly but comparing P4 and P10 shows that early stress clearly affects subsequent drought responses. In P10, drought stressed only at the seed-filling phase, pod yields were increased by 15.1 g/m² per cm of water applied during the stress period, indicating its sensitivity during seed filling and the importance of moisture during this phase. In P4, when the crop was stressed both early and during seed-filling, pod yields were decreased 7.4 g/m² per cm water withheld.

Collaborating with the University of Nottingham, UK, we studied in detail the growth, development, and water-use efficiency of four cultivars, TMV 2, Robut 33-1, NC Ac 17090, and EC 76446(292) under drought conditions. They differed widely in recovery processes after drought stress was remedied (Fig. 3). Research is continuing to further investigate causes of such differences.

Gypsum and Drought Interactions

Previous research showing a cultivar × gypsum × drought interaction was confirmed. In a field experiment, six cultivars were fertilized with gypsum at 0 or 500 kg/ha. Irrigation was applied regularly to all treatments for 60 days after sowing then irrigation was either continued to avoid drought stress or withheld 30 days. Some cultivars but not others benefit significantly from applied gypsum in the event of drought stress at seed filling.

We used three cultivars to investigate reasons for the interaction of cultivar, gypsum, and drought, applying gypsum at three rates, and imposing two drying cycles by the line-source method. During drought in this experiment, gypsum increased pod numbers and development of subterranean pegs (Fig 4), and increased yields in the first drought (Fig 4). When the stress is relieved, gypsum's benefit may be eliminated by subsequent growth. Although gypsum increased pod numbers during an initial drying cycle, subsequent pod growth was inversely related to the number of pods when drought stress was remedied.

Biotic Stresses

Diseases

The most serious diseases of groundnut on a worldwide basis are rust, caused by *Puccinia arachidis*, early leaf spot, caused by *Cercospora arachidicola*, and late leaf spot, caused by *Cercosporidium personatum*. Individually each of those diseases can reduce yields by more than 50%; when they occur together, as they often do, losses can be even worse. The aflatoxin problem is also worldwide. Virus diseases can seriously damage groundnuts but, except for peanut mottle virus (PMV), viruses tend to be restricted in distribution.

Bacterial wilt, caused by *Pseudomonas solanacearum* is important in regions of east Asia, southern Africa, and parts of North America but is apparently absent from many other important groundnut-growing regions. Nematode diseases are not considered important globally but significantly damage groundnuts in restricted areas and may be linked to pod and root rots.

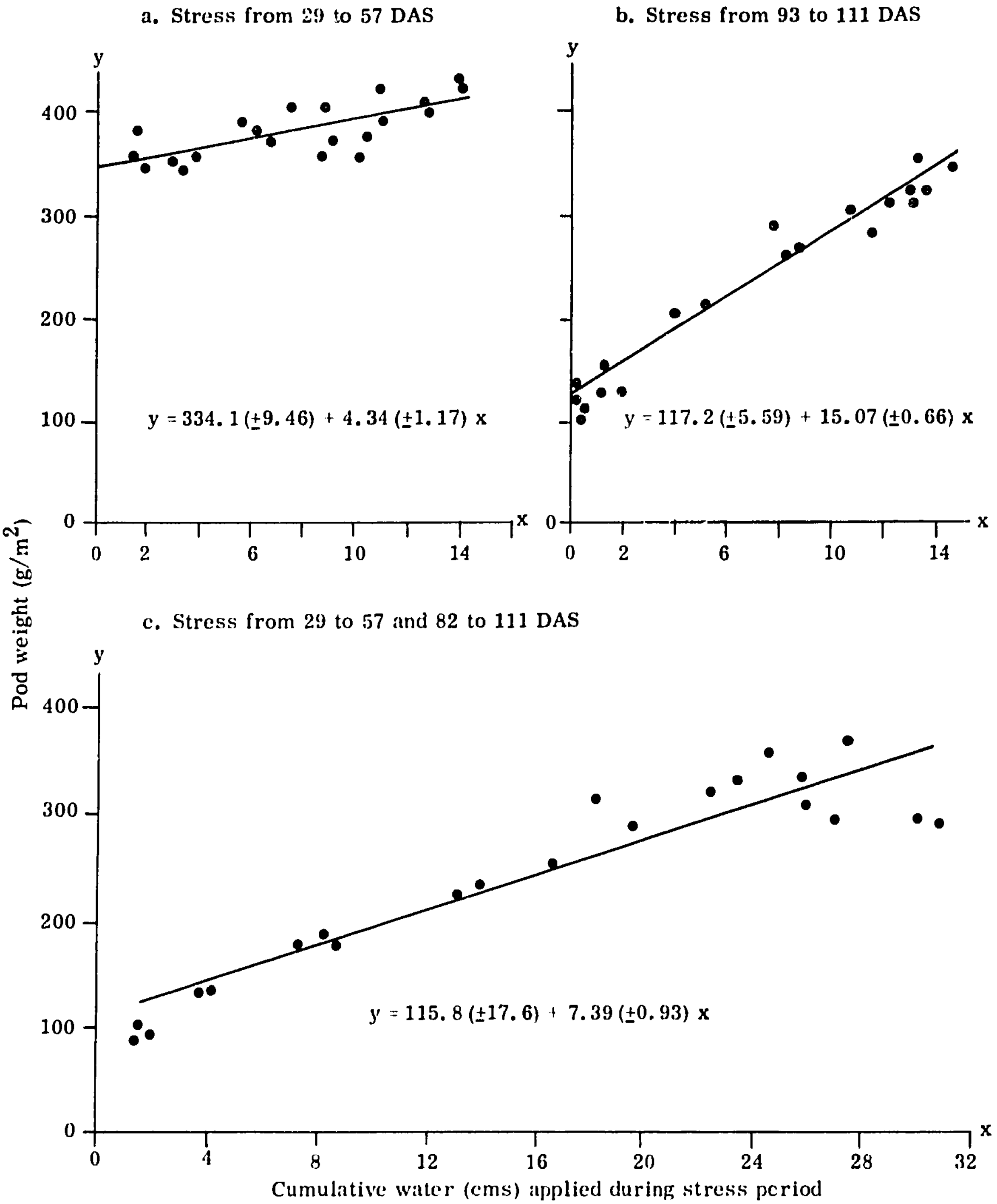


Figure 2. Effects of timing and duration of single and multiple droughts on groundnuts, ICRISAT Center, post-rainy season 1982/83.

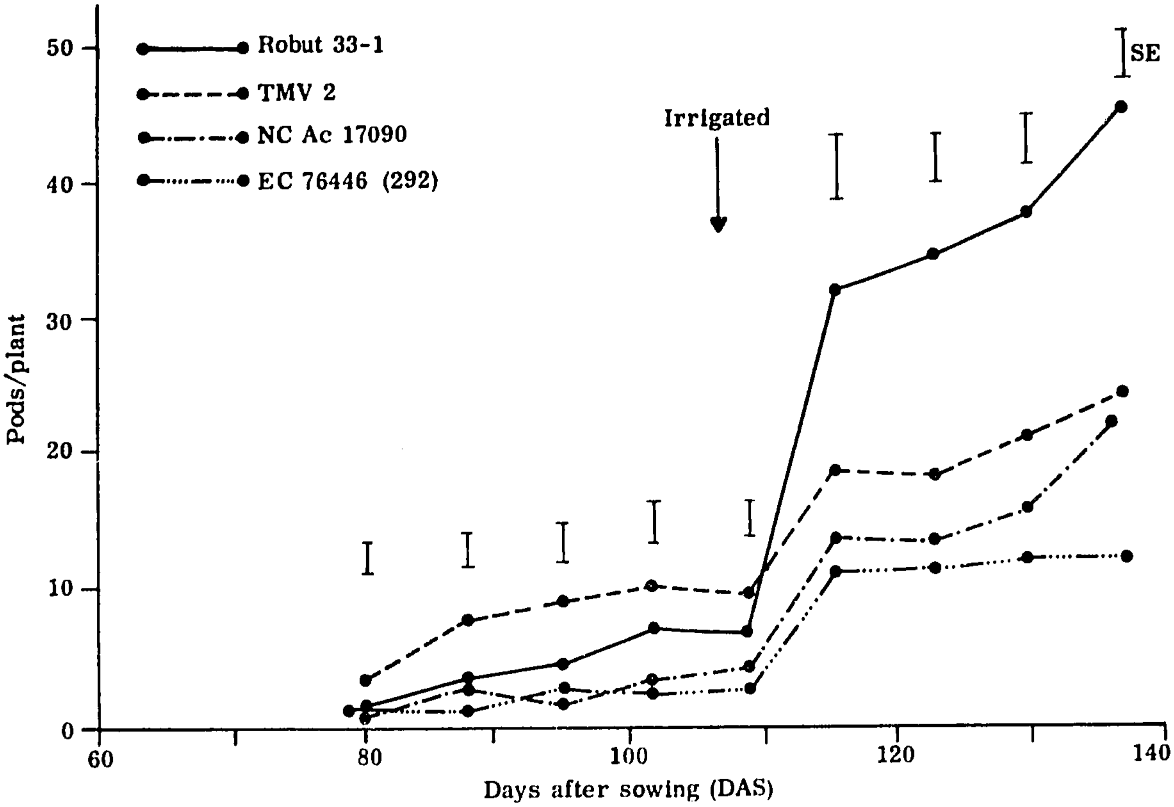


Figure 3. Pods developed with time by four groundnut cultivars during drought stress and after irrigation. ICRISAT Center, postrainy season 1982/83.

Research at ICRISAT Center has been largely determined by the occurrence and severity of particular diseases in India with priority given to work on foliar diseases, pod rots, aflatoxin contamination, and virus diseases.

Foliar Fungal Diseases

Resistance screening. Germplasm lines previously identified as resistant to rust and late leaf spot diseases (ICRISAT Annual Report 1981, pp. 159-160) were further tested in the 1983 rainy season. In addition to the usual heavy rust and late leaf spot attacks, early leaf spot attack was also severe, which permitted meaningful field evaluations for resistance to that disease. Reactions of the lines to rust and late leaf spot were similar to those recorded in previous years, indicating stable resistance (Table 2). None of the lines resisted early leaf spot, including NC 3033, PI 270806, PI 259747, and PI 350680, reported resistant in the USA (Table 2).

Eleven advanced-generation breeding lines that resisted rust and/or late leaf spot in earlier screening trials at ICRISAT Center were further tested in unreplicated trials for resistance to those diseases and to early leaf spot in the 1983 rainy season (Table 3). Eight lines showed high resistance to rust and late leaf spot, and three to rust and early leaf spot.

Yield evaluation of resistant lines. Forty-five germplasm lines with resistance to rust and/or late leaf spot and three released Indian cultivars susceptible to those diseases were again evaluated for yield in the 1982/83 postrainy and 1983 rainy seasons. The trials were fully replicated and protected from insect pests as necessary. Foliar disease incidence was negligible in the postrainy but severe in the rainy season. Yields of dried pods and haulms for some entries are shown in Table 4. Many rust- and late leaf spot-resistant lines outyielded susceptible released cultivars in the rainy season trial.

Selections from wild species derivatives. Forty-three of the 52 Cytogenetics Selection (CS) lines grown at ICRISAT Center and Bhavanisagar in 1982 (ICRISAT Annual Report, 1982 pp.219-221), 3 control cultivars, and 18 newly selected advanced lines were grown in replicated field trials at ICRISAT Center and Bhavanisagar in the 1983 rainy season. Late leaf spot was more severe than in 1982 at Bhavanisagar, where 21 CS lines and 12 new selections had significantly less leaf spot than the controls; 5 lines were selected as sources of resistance for further crosses. Among the 61 derivatives of wild species (one *A. batizocoi* derivative, 8 *A. batizocoi* × *A. spegazzinii* derivatives, and 52 *A. cardenasii* derivatives) 54 lines were resistant to rust at ICRISAT. These 54 lines (one *A. batizocoi* derivative, 7 *A. batizocoi* × *A. spegazzinii* derivatives and 46 *A. cardenasii* derivatives) included 7 *A. cardenasii* derivatives which yielded significantly more than the controls.

Sixty early generation lines (7 selections from the interspecific hybrids of *A. hypogaea* × (*A.*

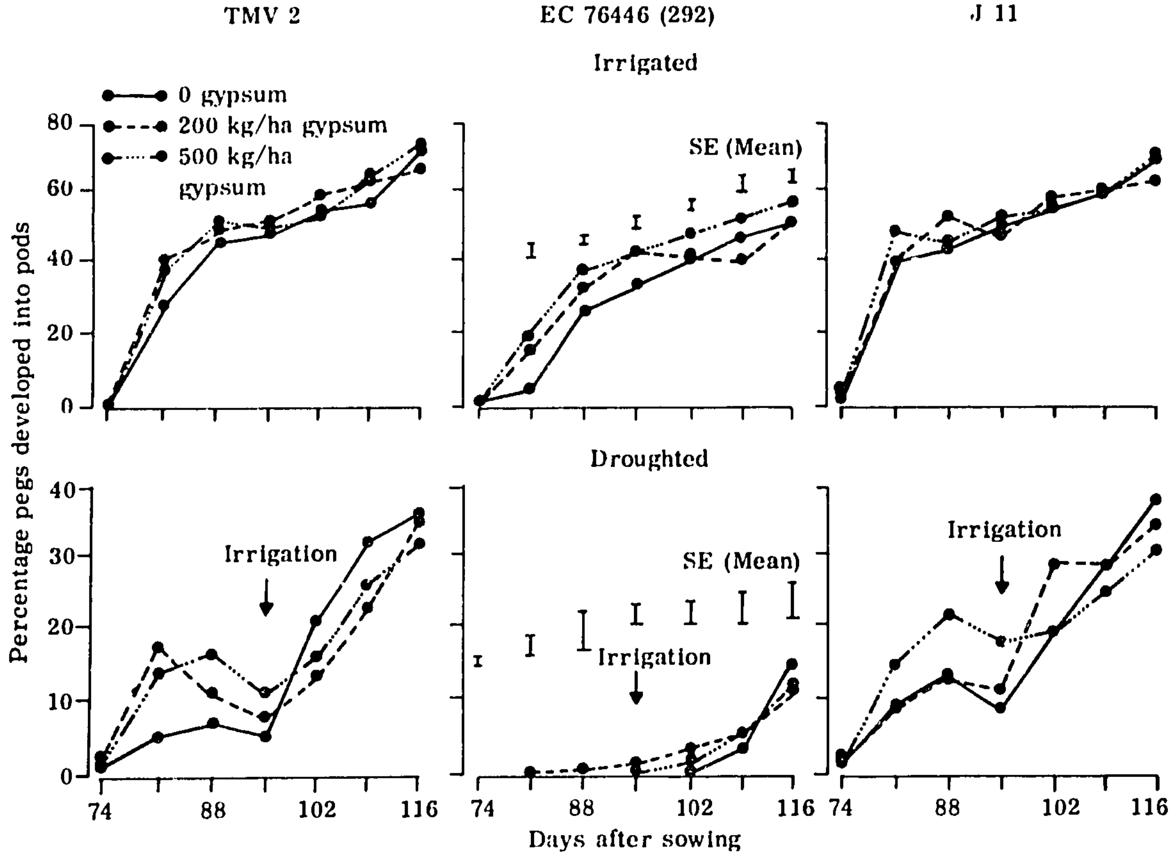


Figure 4. Changes with time in the percentage of subterranean pegs developed into pods for groundnut cultivars grown in wet (T_1) and dry (T_4) conditions after gypsum applications at early flowering, ICRISAT Center, postrainy season 1981/82.

Table 2. Rust, early leaf spot, and late leaf spot reactions of some groundnut genotypes in field screening trials, ICRISAT Center, rainy season 1983.

	Disease scores[1]				Disease scores		
Genotypes	Rust	Early leaf spot	Late leaf spot	Genotypes	Rust	Early leaf spot	Late leaf spot
NC Ac 17090	2.7	8.7	5.7	PI 215696	3.7	8.0	3.3
PI 259747	2.7	7.3	3.0	Krap.St.16	3.7	8.3	3.7
PI 390593	2.7	8.0	4.7	NC Ac 17132	4.0	8.0	3.3
PI 393646	2.7	8.7	6.3	NC Ac 17135	4.0	7.3	3.7
PI 405132	2.7	7.0	3.0	NC Ac 17127	4.3	9.0	4.3
PI 414332	2.7	8.0	6.0	PI 298115	4.3	8.3	7.7
EC 76446(292)	3.0	7.7	3.0	NC Ac 17129	4.7	9.0	4.3
PI 350680	3.0	7.0	3.3	PI 393516	4.7	8.3	3.3
PI 314817	3.0	8.7	6.3	NC Ac 17506	4.7	8.3	3.7
PI 315608	3.0	7.3	6.7	NC Ac 17142	5.0	8.0	4.3
PI 341879	3.0	8.7	3.3	C. No.45-23	6.3	8.3	5.3
PI 381622	3.0	8.0	3.3	NC Ac 17502	7.3	7.3	5.3
PI 393517	3.0	7.7	6.7	NC Ac 15989	8.3	7.0	3.7
PI 393527 B	3.0	8.7	6.7	RMP 12	8.3	6.7	4.0
PI 393643	3.0	7.3	6.7	NC 3033	9.0	8.0	9.0
PI 407454	3.0	8.7	6.7	EC 76446 Sp	9.0	8.7	9.7
PI 414331	3.0	8.7	7.3				
NC Ac 17133 RF	3.3	7.7	3.3	TMV 2[2]	9.0	9.0	9.0
NC Ac 927	3.3	8.7	3.3	J 11[2]	9.0	9.0	9.0
USA 63	3.3	8.0	3.0	JL 24[2]	9.0	8.7	9.0
				Robut 33-1[2]	9.0	8.6	8.3
PI 390595	3.3	8.0	3.3				
PI 270806	3.7	7.3	3.3				
PI 393526	3.7	8.3	5.7	SE	±0.24	±0.36	±0.27
PI 393531	3.7	8.3	6.7				
PI 393641	3.7	7.7	4.7	CV(%)	9	8	9

1. Mean of field disease scores on a 9-point scale; 1 = no disease and 9 = 50 to 100% foliage destroyed.
2. Foliar disease susceptible, released, high yielding cultivars.

batizocoi × *A. spegazzinii*) and 53 from *A. hypogaea* × *A. cardenasii*) were compared with 4 controls in a replicated field trial at ICRISAT Center; 52 lines resisted rust (5 selections from *A. hypogaea* × (*A. batizocoi* × *A. spegazzinii*) and 47 from *A. hypogaea* × *A. cardenasii*). Three *A. cardenasii* derivatives significantly outyielded the controls.

Thirty-four selections from interspecific crosses (4 selections from *A. hypogaea* × (*A. batizocoi* × *A. spegazzinii*) and 30 from *A. hypogaea* × *A. cardenasii*) were sown in a replicated field trial at ICRISAT Center to assess reactions to foliar diseases; 32 selections were resistant to rust (4 from *A. hypogaea* × (*A. batizocoi* × *A. spegazzinii*) and 28 from *A. hypogaea* × *A. cardenasii*). One *A. batizocoi* × *A. spegazzinii* derivative, and 14 *A. cardenasii* derivatives yielded significantly more than the controls.

From the 155 lines selected for rust resistance in 1982 (one *A. batizocoi* derivative; 19 *A. batizocoi* and *A. spegazzinii* derivatives, and 135 *A. cardenasii* derivatives) 138 (one *A. batizocoi* derivative; 16 *A. batizocoi* × *A. spegazinii* deriva-

Table 3. Rust, early leaf spot, and late leaf spot reactions of some groundnut breeding lines in field screening trials, at ICRISAT Center, rainy season 1983.

	Disease scores (1-9)		
Pedigree	Rust	Early leaf spot	Late leaf spot
(TG 3 × EC 76446 (292))F_2-B_2-B_1-B_2-B_3-B_1-B_1	2	2	2
(OG69-6-1 × NC Ac 17090)F_2-B_1-B_2-B_2-B_1-B_1	2	2	5
(Argentine × PI 259747)F_2-P61-P2	3	3	8
(Argentine × PI 259747)F_2-P152	2	7	3
(NC Ac 2750 × PI 259747)F_2-P92	3	8	3
(X14-X-X-1-B × PI 259747)F_2-B_1-B_1-B_2-B_1-B_1	2	8	3
(JH 335 × EC 76446 (292))F_2-B_1-B_2-B_2-B_1-B_1	2	9	3
(Variety 99-5 × PI 259747)F_2-P108-P_1-B_1-B_2-B_1-B_1-B_1	2	8	3
(OG 71-3 × NC Ac 17090)F_2-B_2-B_1-B_1-B_1	2	7	3
(NC Ac 1107 × NC Ac 17090)F_2-B_1-B_1-B_1-B_1-B_1-B_1	2	7	3
TMV 2[1]	9	9	9
Robut 33-1[1]	9	9	9

1. Foliar disease susceptible, released, high-yielding cultivars.

Table 4. Yields (kg/ha) of some groundnut genotypes resistant and susceptible to foliar diseases, ICRISAT Center, postrainy season 1982/83 and rainy season 1983.

	Pods		Haulms	
Genotypes	1982/83	1983	1982/83	1983
PI 314817	5610	1530	7100	1780
PI 393643	4830	1550	6920	2050
PI 393517	4610	910	7180	1530
PI 407454	4460	1550	9050	2070
PI 393531	4450	1450	6530	1430
PI 393527 B	4440	1240	6320	2070
PI 390593	4400	1400	7400	2300
NC Ac 17142	4300	1250	7480	1900
PI 393646	4230	1720	8610	1300
PI 259747	4210	1330	8500	2540
TMV 2[1]	4270	850	5990	910
J 11[1]	4180	1100	5658	910
Robut 33-1[1]	2990	1010	9980	1060
SE	±278	±130	±560	±233
Trial mean[2]	3750	1290	8090	2070
CV(%)	9	18	8	20

1. Foliar disease-susceptible, released, high-yielding cultivars.
2. Mean yield of 45 entries in trial 1982/83 and 46 entries in the rainy season 1983.

tives, and 121 *A. cardenasii* derivatives) were resistant to rust in 1983, and 25 of them (one *A. batizocoi* × *A. spegazzinii* derivative and 24 *A. cardenasii* derivatives) yielded significantly more than the controls. Thirty-three selections (4 *A. batizocoi* × *A. spegazzinii* derivatives and 29 *A. cardenasii* derivatives) had significantly less late leafspot than the susceptible controls. Selected lines will be used as parents in backcross and pedigree selection programs in 1984.

Breeding for resistance. A total of 256 new crosses (100 in the 1982/83 postrainy season and 156 in the 1983 rainy season) were made with stable interspecific derivatives and advanced breeding lines as sources of rust and late leafspot resistances. During the postrainy season 30 F_1 and 593 F_3 to F_{10} populations were advanced without selection. In the rainy season 918 F_2 to F_{11} populations were planted in the foliar disease nursery. A heavy incidence of bud necrosis disease precluded proper yield evaluations. Still we selected 324 good yielding and 808 average yielding, resistant and moderately resistant bulks, and 228 sub-bulks based on plant habit and other morphological characters. Despite bud necrosis damage, we have 1360 progenies to be advanced during the 1983/84 postrainy season.

Resistant selections yield trials. During the 1983 rainy season nine foliar disease-resistant yield trials were conducted at ICRISAT Center under both high input (60 kg P_2O_5/ha, irrigation, and insecticides when required) and low input (20 kg P_2O_5/ha, rainfed with no insecticides) conditions. We evaluated 272 resistant selections whose performances are compared with Robut 33-1 and JL 24 controls and with resistant NC Ac 17090 in Table 5. Several resistant selections were superior under both high and low input conditions.

Rust-resistant selections yield trial. Yields of some rust-resistant selections from high and low input trials are given in Table 6. The selections (RMP-91 × Dht-200)-F_6-B(S2), (An-65 × NC Ac 17090)-F_8-B, (JH 60 × PI 259747)-F_9-B, and NC-Fla-14 × NC Ac 17090)-F_9-B and the two interspecific stable derivatives of *Arachis hypogaea* × *A. cardenasii*, CS 16-B and CS 13-B, all did well at both input levels.

Late leaf spot and rust-resistant selection yield trials. Thirty advanced breeding lines, most of them with acceptable pod and kernel characteristics, showed resistance to both late leaf spot and rust. Nine of them outyielded either the standard susceptible controls and/or the resistant parent. Yield levels of some of these lines are given in Table 7. Most of them have acceptable pod and kernel characters.

Multilocation advanced lines trial. To check yield stability, we tested 46 foliar disease-resistant, advanced lines under high and low input conditions at ICRISAT Center and three other locations in India, Anantapur, Bhavanisagar, and Dharwar. Sixteen resistant lines gave higher mean yields than the best susceptible control cultivar, Robut 33-1, and three were better than the resistant parent, NC Ac 17090 (Table 8). The stability of two rust- and late leaf spot-resistant lines, (Var 2-5 × PI 259747)-F_{10}-B and GAUG 1 × PI 259747)-F_9-B(S2) was superior to that of adapted susceptible controls, as judged by the method of Eberhart and Russell (1966).

Table 5. Summary of the foliar disease-resistant advanced groundnut lines yield trials, ICRISAT Center, rainy season 1983.

Trial	No. of resistant selections tested	Number of lines significantly outyielding					
		NC Ac 17090[1]		Robut 33-1[2]		JL 24[2]	
		HI[3]	LI[4]	HI	LI	HI	LI
$F_{6/7}$	21	0	7	9	3	16	20
F_8	35	1	3	25	3	14	30
F_9	60	4	0	52	13	56	57
F_{10}	37	0	4	10	6	8	31
F_{10} Rainfed selections	15	0	0	0	2	4	14
F_{11}	22	0	0	7	1	13	13
F_{11} Rainfed selections	19	2	2	3	6	3	17
Multilocation trial	46	0	13	14	1	10	39
FDRVT	17	--	-	3	3	9	6

1. Rust resistant control.
2. Susceptible controls.
3. HI = High input (60 P_2O_5/ha with irrigation and sprays).
4. LI = Low input (20 P_2O_5/ha rainfed and no insecticide sprays).
5. Not included in trial.

Table 6. Performance of some rust-resistant advanced groundnut lines at ICRISAT Center, rainy season 1983.

Trial	Pedigree	Yield (kg/ha) HI[1]	Yield (kg/ha) LI[2]	Rust reaction (1-9)[3]
$F_{6/7}$	(RMP-91 × Dht-200)-F_6-B(S_1)	4060	1970	3.2
	(RMP-91 × Dht-200)-F_6-B(S_2)	3730	2180	3.0
	(Robut 33-1 × PI 298115) F_5-B	3650	2060	3.5
	NC Ac 17090[4]	3890	1570	3.2
	Robut 33-1[5]	2810	1716	6.7
	JL 24[5]	2190	780	5.7
	SE	±142	±119	±0.4
	Trial mean	3640	1610	3.9
	CV (%)	8	13	19
F_{10} rainfed selections	(NC-Fla-14 × NC Ac 17090)F_9-B	3150	1790	3.7
	(Tifspan × NC Ac 17090) F_9-B	3060	1320	3.0
	(GAUG-1 × PI 259747) F_9-B	2430	1930	4.0
	NC Ac 17090[4]	3240	1750	3.2
	Robut 33-1[5]	2670	1490	7.2
	JL 24[5]	2290	840	7.0
	SE	±197	±94	±0.3
	Trial mean	2520	1430	4.0
	CV (%)	13	11	14
F_9	(Ah 65 × NC Ac 17090) F_8-B	4160	2200	3.3
	(NC Ac 2190 × NC Ac 17090) F_8-B	4150	2020	3.2
	(JH 60 × NC Ac 17090) F_8-B	3340	2240	3.2
	NC Ac 17090[4]	3290	2040	2.8
	Robut 33-1[5]	2410	1620	8.3
	JL 24[5]	2280	1010	7.7
	SE	±165	±148	±0.4
	Trial mean	3160	1790	3.6
	CV (%)	9	14	21
F_{10}	(NC Ac 1107 × NC Ac 17090) F_9-B	4070	2080	2.8
	(JH 60 × PI 259747) F_9-B	3850	2530	2.8
	(Ah 65 × NC Ac 17090) F_9-B	2740	2470	3.0
	NC Ac 17090[4]	3670	1820	3.0
	Robut 33-1[5]	2560	1740	4.7
	JL 24[5]	2710	1080	4.7
	SE	±182	±144	±0.3
	Trial mean	2890	1830	3.1
	CV (%)	11	14	16

1. See Table 4 footnote 3.
2. See Table 4 footnote 4.
3. Recorded from rainfed trials.
4. Rust-resistant control.
5. Rust-susceptible control.

Varietal trial. Seventeen advanced foliar disease-resistant ICRISAT selections were tested, with other breeders' selections and resistant germplasm lines, by the All India Coordinated Research Project on Oilseeds (AICORPO) at eight locations in India during the 1983 rainy season. At ICRISAT Center the trial was conducted under both high and low input conditions. Selections ICG (CG; FDRS)-17 and ICG (FDRS)-10, significantly out-yielded (more than 3000 kg/ha pod yields), all three susceptible control cultivars (Table 9).

Soilborne Fungal Diseases

Pod Rot

In the 1982/83 postrainy season we screened 500 more germplasm lines for resistance to the group

Table 7. Performance of some rust and late leaf spot-resistant groundnut lines, ICRISAT Center, rainy season 1983.

		Yield (kg/ha)					Reaction (1-9)	
Trial	Pedigree	HI[1]	LI[2]	Haulm wt (kg/ha)[3]	Shelling (%)[3]	100-Kernel wt (g)[4]	Rust	Late leaf spot
F_8 Trial	(SM-1 × NC Ac 17090) F_7-B	3440	2290	1990	72	27.0	2.8	3.7
	(NC-Fla 14 × NC Ac 17090) F_7-B	3340	1880	2390	64	26.1	2.8	4.0
	NC Ac 17090[5]	3690	1430	1900	68	28.1	2.8	8.0
	Robut 33-1[6]	2260	1620	1630	75	30.7	6.7	8.8
	SE	±174	±131	±150			±0.4	±0.4
	CV (%)	10	14	13			20	11
F_{10} Trial	(NC Ac 2190 × PI 259747) F_9-B	3120	1410	1710	66	31.1	3.5	4.8
	(X9-2B-25-B × PI 259747) F_9-B	1980	2080	2690	71	28.2	3.1	4.8
	(Spancross × PI 259747) F_9-B	2750	2080	2040	70	26.3	3.2	4.2
	(NC Ac 17090)[5]	3670	1820	2320	69	31.4	3.0	7.7
	Robut 33-1[6]	2560	1740	1580	73	32.5	4.7	9.0
	SE	±182	±145	±155			±0.3	±0.5
	CV (%)	11	14	13			16	13
F_{11} Trial	(Var 99-5 × PI 259747) F_{10}-B[7]	2640	1850	1650	70	35.3	3.7	4.3
	(Var 2-2 × PI 259747) F_{10}-B[8]	2580	1760	1810	73	30.6	4.5	4.2
	NC Ac 17090[5]	3640	2030	2460	69	31.2	3.0	7.5
	Robut 33-1[6]	2970	1540	1570	69	29.3	6.7	8.8
	SE	±197	±120	±126			±0.5	±0.5
	CV (%)	13	12	11			20	12

1. See Table 4 footnote 3.
2. See Table 4 footnote 4.
3. Recorded from LI trials.
4. See Table 5 footnote 3.
5. Resistant control.
6. Susceptible control.
7. Selection from irrigated fields.
8. Selected from rainfed fields.

of fungi which cause pod rot in a replicated field trial at ICRISAT Center. Disease levels were low but we selected 100 lines for advanced screening.

Long-term evaluation of lines previously identified as pod rot resistant (ICRISAT Annual Report 1982, p. 185) continued in both the 1982/83 postrainy and the 1983 rainy seasons. Pod rot incidence was low but pod rot-resistant entries had significantly less rot than the susceptible controls.

The Aflatoxin Problem

Dry seed resistance screening. We screened 350 more genotyopes for resistance of dry seeds to invasion by the aflatoxin-producting fungus, *Aspergillus flavus* using techniques described previously (ICRISAT Annual Report 1979/80 pp.155-156) but found no resistant genotype.

Effects of time harvested and windrow drying. Over the four rainy seasons in the period 1979 to

Table 8. Performance of some rust and late leaf spot-resistant, advanced lines at five locations in India, rainy season 1983.

	Yield (kg/ha)						Disease reaction at ICRISAT (1-9 scale)[1]	
Pedigree	ICRISAT (irrigated)	ICRISAT (rainfed)	Anantapur (rainfed)	Dharwar (rainfed)	Bhavanisagar (irrigated)	Mean	Rust score	Late leaf spot score
(JH 335 × NC Ac 17090) F_9-B	3800	2540	1710	3010	3870	2986	3.5	7.5
(JH 171 × NC Ac 17090) F_8-B	2980	2220	2280	2520	3620	2980	3.0	5.5
(Ah 6279 × PI 259747) F_9-B	3990	2500	1600	2490	3660	2848	5.0	7.0
(JH 60 × PI 259747) F_{10}-B	3040	2290	1610	2770	4170	2776	3.0	7.0
(RS 114 × PI 259747) F_8-B	4260	2050	1630	2410	3270	2724	3.0	6.0
(SM 1 × EC 76446(292)) F_9-B	3350	1850	1720	3500	3060	2696	6.5	8.0
(GAUG 1 × PI 259747) F_9-B(S_1)	3710	2610	1580	2330	3230	2692	4.0	6.0
(NC Ac 2190 × NC Ac 17090) F_8-B(S_1)	3530	2300	1660	2810	2840	2628	3.0	8.0
(NC Ac 2190 × NC Ac 17090) F_8-B(S_2)	3700	2030	1780	2550	3040	2620	4.0	7.0
(NC Ac 2768 × PI 259747) F_{10}-B(S_1)	3790	1940	1800	2750	2780	2612	3.0	6.5
(NC Ac 2768 × PI 259747) F_{10}-B(S_2)	3650	2140	1440	3510	2290	2606	3.7	6.0
NC Ac 400 × EC 76446(29) F_9-B	3460	2090	1580	2580	3290	2600	2.8	7.8
(Var.25 × PI 259747) F_{10}-B	3310	2470	1800	2330	3020	2586	4.0	4.8
(FSB 72 × NC Ac 17090) F_8-B	3130	1990	1630	2450	3700	2580	2.8	6.5
(NG 268 × NC Ac 17090) F_9-B	2800	2030	2210	3040	2600	2536	3.5	6.7
(GAUG 1 × PI 259747) F_9-B(S_2)	2870	2390	1640	2520	3140	2512	3.5	4.7
Controls								
NC Ac 17090[2]	3870	1740	1710	3320	3300	2788	3.0	7.5
Robut 33-1[3]	2600	2150	1830	2990	2850	2484	7.0	9.0
JL 24[3]	2890	1340	1870	2190	3460	2350	8.0	9.0
SE	±203	±143	±115	±200	±208			
Trial mean	2990	1980	1650	2380	2960			
CV (%)	12	13	12	15	12			

1. From ICRISAT Center rainfed trial.
2. Rust and late leaf spot-resistant control.
3. Rust and late leaf spot-susceptible control.

Table 9. Groundnut foliar disease resistance varietal trial, ICRISAT Center, rainy season 1983.

Pedigree	Yield (kg/ha) HI[1]	Yield (kg/ha) LI[2]	Shelling (%)[3]	Reaction to Rust[4]	Reaction to Late leaf spot
ICG (CG;FDRS)-17	3600	3530	60	5.5	6.0
ICG (FDRS)-10	3530	3250	63	2.8	7.9
ICG (FDRS)-12	3420	1880	61	2.8	7.4
ICG-7898	3310	1710	56	3.1	7.3
ICG-7882	3190	2220	60	3.1	7.8
ICG (CG;FDRS)-18	3170	3360	64	5.9	6.1
ICG (FDRS)-15	3140	1920	58	3.8	8.5
ICG (FDRS)-4	3100	2620	58	3.0	7.5
ICG (FDRS)-8	3080	2350	59	3.3	7.6
ICG (FDRS)-2	3070	1860	58	3.3	8.1
ICG (FDRS)-11	3010	2560	65	3.6	7.9
ICG (FDRS)-5	2880	2690	58	2.5	7.8
CCG-4007	2800	2130	63	2.8	7.9
ICG (FDRS)-7	2710	1350	64	3.1	7.6
ICG (FDRS)-13	2680	1810	62	3.3	8.1
ICG (FDRS)-9	2630	1910	61	2.9	8.0
ICG (FDRS)-6	2640	1570	62	2.9	7.1
ICG (FDRS)-16	2430	1800	62	2.6	8.0
ICG (FDRS)-1	2410	2010	61	3.9	8.0
ICG (FDRS)-14	2360	1390	59	3.1	6.5
Controls					
Robut 33-1[5]	2730	2250	59	8.3	8.9
JL 24[5]	2380	1840	58	9.0	9.0
J 11[5]	2110	1720	62	9.0	9.0
SE	±204	±189	±2	±0.2	±0.2
Trial mean	2880	2160			
CV (%)	12	18	5	12	4

1. See Table 4 footnote 3.
2. See Table 4 footnote 4.
3. Recorded from LI trial.
4. See Table 1 footnote 1.
5. Rust and late leaf spot-susceptible controls.

1982, we recorded seed infection with *A. flavus* of immature, mature, and over-mature seeds of several groundnut genotypes with various levels of resistance to *A. flavus*. In general, genotypes with dry seed resistance had fewer seed infected at lifting than had the other genotypes. Infection with *A. flavus* increased with maturity of seeds (Tables 10 and 11). In the 1983 rainy season we examined effects of seed maturity and drying time in the windrow on seed infection with *A. flavus* and contamination with aflatoxin by sowing four genotypes, J 11 (resistant to pod rot and to seed invasion by *A. flavus*), EC 76446(292), M 13, and TMV 2, in a replicated trial. Four harvest dates used were: normal harvest, 30 and 10 days earlier, and 10 days later. Seeds from nor-

Table 10. Effects of groundnut seed maturity on seed infection by *Aspergillus flavus*, ICRISAT Center, rainy seasons 1979 and 1980.

	Seeds infected by *A. flavus* (%)					
	Immature crop		Mature crop		Overmature crop	
Genotypes	1979	1980	1979	1980	1979	1980
PI 337394F[1]	0.0[4]	0.0[4]	0.3	0.3	0.3	1.3
PI 337409[1]	0.0	0.0	0.0	0.3	0.3	1.0
J 11	0.0	0.0	0.0	0.0	0.0	1.3
NC 3033[2]	0.7	1.0	2.0	1.0	3.3	3.3
Florigiant[2]	0.3	1.0	1.0	1.0	2.7	2.0
PI 259747[2]	1.3	2.0	2.0	2.0	4.0	4.7
NC Ac 17090[2]	1.3	2.0	2.3	2.0	5.7	4.7
EC 76446(292)[2]	2.0	1.7	2.3	2.3	6.0	6.7
TMV 2[2]	1.0	1.0	1.7	1.0	3.0	2.7
OG 43-4-1[3]	1.7	1.3	2.0	1.7	3.0	3.0

SE for 1979 genotypes ±0.24

SE for 1980 genotypes ±0.26

1. Genotypes with dry seed resistance.
2. Susceptible control.
3. Highly susceptible control.
4. Zero values not used in calculation of SE.

mal harvest and harvest 10 days later were tested for infection with *A. flavus* and aflatoxin content when lifted and after 2, 4, and 6 days of windrow drying. The genotype J 11 was least infected with *A. flavus* and least contaminated with aflatoxin (Tables 12 and 13). Seed invasion by *A. flavus* and seed maturity increased together.

Breeding for resistance to *A. flavus*. Our crossing work this year involved *A. flavus*-resistant lines and other lines resistant to rust, leaf spots, and various pests—to incorporate resistance to those serious yield reducers. Several new crosses were also made with *A. flavus* dry seed-resistant source lines (J 11, Var.27, Ah 7223) and some of their advanced-generation derivatives with the high yielding lines developed under other projects—to raise the yield potential of *A. flavus*-resistant source lines. We made 58 crosses and grew and made selections in more than 200 bulk progenies from segregating generations from F_2 to F_7.

We tested 30 and 34 advanced generation breeding lines in yield trials at ICRISAT Center during the postrainy season 1982/83 and the rainy season 1983. In the rainy season, we used irrigated and nonirrigated conditions. Seed colonization was higher under nonirrigated than irrigated conditions. Six lines were selected in the first season, nine in the second, for further testing as their seed colonization was consistently lower than the resistant controls, J 11 and UF 71513-1 (Tables 14 and 15).

Virus Diseases

Bud Necrosis

We have not found any genotype resistant to tomato spotted wilt virus, that causes bud necrosis disease (BND) of groundnut, but we have

Table 11. Effects of groundnut seed maturity on seed infection by *A. flavus*, ICRISAT Center, rainy seasons 1981 and 1982.

	Seeds infected by *A. flavus* (%)					
	Immature crop		Mature crop		Overmature crop	
Genotypes	1981	1982	1981	1982	1981	1982
PI 337394F[1]	0.3	0.3	0.7	0.3	2.0	2.3
PI 337409[1]	0.0	-[4]	1.0	-	2.3	-
UF 71513[1]	0.0	0.0	0.7	0.7	1.3	3.0
J 11[1]	0.0	0.3	0.3	0.7	1.6	3.3
Ah 7223[1]	0.0	0.0	0.3	0.3	1.6	4.3
U 4-47-7[1]	0.7	-	1.0	-	3.3	-
Var. 27[1]	-	0.7	-	1.3	-	6.0
C 55-437[1]	-	0.0	-	1.0	-	6.0
Faizpur[1]	-	0.3	-	1.0	-	4.3
TMV 2[2]	1.3	1.0	2.0	2.3	5.0	8.0
EC 76442(292)[2]	1.3	2.3	2.0	4.3	6.0	11.7
Gangapuri[2]	1.3	2.3	2.0	3.6	5.0	8.7
OG 43-4-1[3]	2.0	-	2.0	-	4.0	-

SE for 1981 genotypes ±0.28

SE for 1982 genotypes ±0.53

[1] Resistant or moderately resistant to seed colonization by *A. flavus*.
[2] Susceptible control.
[3] Highly susceptible control.
[4] Not tested.

Table 12. Effects of groundnut seed maturity on seed infection with *A. flavus* and aflatoxin content, field trial at ICRISAT Center, rainy season 1983.

	Seed infected by *A. flavus* and their aflatoxin content (%)			
	Immature crop		Mature crop (Days relative to maturity)	Overmature crop
Genotype	-30	-100	0	+100
TMV 2	1.3[1] (0.0)[2]	3.7 (0.0)	3.3 (7.3)	9.3 (14.6)
J 11	0.0 (0.0)	0.7 (0.0)	0.3 (2.4)	3.3 (11.7)
EC 76446 (292)	2.0 (0.0)	4.3 (1.3)	5.0 (7.4)	9.7 (13.0)
M 13	2.0 (0.0)	[illegible].3 (2.4)	3.7 (12.0)	8.0 (14.6)
SE		Seed infection ±0.27		Aflatoxin content ±1.80

[1] Seed infection with *A. flavus*.
[2] Aflatoxin B1 content inμg/kg.

found wide differences among genotypes in field incidence of BND. Results of screening trials with groundnut germplasm and breeding lines to identify field resistance are reported under "Insect Pests."

Effect of BND on yield. In a replicated postrainy season 1982/83 yield trial, BND incidence was varied in different plots by applying dimethoate insecticide at various concentrations at different intervals. Numbers of plants in all plots ranged from 871 to 880. Substantial reductions in pod and haulm yields from BND are shown in Table 16.

We attempted to estimate yield losses from BND in Andhra Pradesh by stratified random sampling of 6 fields in each of 11 districts. The observations were divided into two strata: plants with (1) early- or (2) late-infection symptoms. Early-infected plants were assumed to contribute 90% yield loss; late-infected ones, 50%. Total estimated loss was US $4.6 million, with the highest loss (US $1.7 million) in Nalgonda district, the lowest in Nellore district.

Table 13. Effects of groundnut seed maturity and windrow drying on seed infection by *A. flavus* and aflatoxin content, field trial, ICRISAT Center, rainy season 1983.

	Seeds infected by *A. flavus* and aflatoxin content					
	Mature crop (days in windrow)			Overmature crop (days in windrow)		
Genotype	2	4	6	2	4	6
TMV 2	2.0[1]	3.3	4.0	8.0	9.7	9.3
	(6.1)[2]	(8.0)	(10.2)	(15.0)	(12.6)	(12.9)
J 11	0.3	0.3	0.7	3.3	4.7	4.3
	(2.4)	(2.0)	(3.3)	(13.0)	(8.6)	(9.3)
EC 76446 (292)	4.7	4.3	5.0	9.7	9.0	9.0
	(7.0)	(8.6)	(10.9)	(16.0)	(13.0)	(12.0)
M 13	4.0	4.7	4.0	8.0	8.3	9.0
	(11.3)	(13.3)	(10.4)	(15.3)	(15.3)	(17.3)
	Seed infection			Aflatoxin content		
SE	±0.28			±1.60		

1. Seeds infected by *A. flavus* (%).
2. Aflatoxin B1 content in µg/ha.

Table 14. Groundnut pod yields and percentage seed colonization by *A. flavus* of selected breeding lines, ICRISAT Center, postrainy season 1982/83.

Pedigree	Pod yield (kg/ha)	% seed colonization
(MH 2×PI 337409)F_8B_1	5060	19
(MH 2×PI 337394F)F_7B_1	5000	15
(PI 337409×UF 71513-1)F_4B_1	5160	18
(UF 71513-1×PI 337394F)F_4B_1	4800	20
(UF 71513-1×PI 337409)F_5B_1	4430	17
Controls		
Robut 33-1[1]	4280	74
J 11[1]	4820	47
JL 24[1]	4220	58
UF 71513-1[2]	5070	20
SE	±292	±3
Trial mean	4850	45
CV (%)	12	12

1. High-yielding released cultivars.
2. Resistant genotype.

Peanut Clump

Causal agent. We have identified 5 geographically-separated isolates of peanut clump virus (PCV) with different severities on groundnut and that cause different reactions on diagnostic hosts. We purified the virus from all isolates and produced antisera. Immunosorbent electron microscopy and enzyme-linked immunosorbent assay (das-ELISA) tests indicate that three of the isolates are serologically related, while two are distinct.

Transmission. The fungus *Polymyxa graminis* has been found in all PCV-infested soils examined, and several weed and crop plants on PCV-infested soils contain both *P. graminis* and PCV. Groundnut plants grown in sterilized soil containing PCV-infected wheat roots became infected with PCV.

Table 15. Pod yield and percentage seed colonization by *A. flavus* of selected groundnut breeding lines, ICRISAT Center, rainy season 1983.

	Irrigated		Nonirrigated	
Pedigree	Pod yield (kg/ha)	% seed colonization	Pod yield (kg/ha)	% seed colonization
(MGS 7 × PI 337409)F_8B_1	2140	2	410	35
(NC 17 × PI 337394F)F_8B_1	2570	9	750	39
(J 11 × PI 337394F)F_7B_1	2150	8	550	35
(PI 337409 × UF 71513-1)F_4B_1	2310	7	530	29
(J 11 × PI 337394F)F_7B_1	2260	10	730	29
(UF 71513-1 × PI 337394F)F_4B_1	2350	11	520	27
(MH 2 × PI 337394F)F_7B_1	2100	10	350	33
(MH 2 × PI 337394F)F_7B_1	2310	0	570	26
(55-437 × PI 337394F)F_8B_1	2330	5	700	31
Controls				
J 11[1]	1810	12	490	39
JL 24[1]	2230	19	500	43
Robut 33-1[1]	2290	32	690	67
UF 71513-1[2]	2380	12	660	48
SE	±175		±51	
Trial mean	2250		620	
CV (%)	13		14	

1. High-yielding susceptible released cultivars. 2. Resistant genotype.

Resistance screening. In the 1983 rainy season we used naturally-infested soils to screen for PCV resistance: 1050 germplasm and 483 breeding lines at Bapatla, Andhra Pradesh, and 265 breeding lines at Ludhiana, Punjab. None was resistant. Three germplasm lines selected for advanced screening in 1982 (ICRISAT Annual Report 1982, p.189) were susceptible to PCV in

Table 16. Effect of BND on yield of groundnut cv TMV 2, ICRISAT Center, postrainy season 1982/83.

Dimethoate concentration (%)	Application interval (days)	BND incidence at harvest (%)	Yield (kg/ha)	
			Pods	Haulms
0.20	3	42	1570	3120
0.20	5	52	1550	3100
0.20	7	62	1320	2750
0.05	7	74	1140	2340
0.05	10	78	1070	2340
SE		±3	±56	±94
CV(%)		11	8	7

Figure 5. Using a field inoculation technique (above), we identified four groundnut germplasm lines with less than 5% yield losses from peanut mottle virus disease; these will be screened further in 1984.

the 1983 trials at both locations, (Bapatla and Ludhiana).

In 1983 we also screened 18 wild *Arachis* species and 140 interspecific hybrid derivatives for resistance to PCV at Bapatla. All the interspecific derivatives were susceptible but 13 of the *Arachis* species did not become infected, and none of the 5 infected species showed typical PCV symptoms.

Peanut Mottle

Resistance screening. Using a field mechanical-inoculation method, (Fig. 5) we screened 433 germplasm lines in the 1982/83 and 1983 seasons for resistance to peanut mottle virus (PMV). Four lines with less than 5% yield losses will be included in advanced screening trials in 1984.

In the 1982/83 postrainy season we tested for yield five genotypes and two PMV-susceptible controls that were infected with PMV. NC Ac 2240 had no loss in yield; the other four had from 13 to 30%, and the controls had 43 and 55% losses (Table 17). In the 1983 rainy season a similar trial with the four best entries from the previous trial and one susceptible cultivar again showed that NC Ac 2240 suffered the least loss in yield from PMV.

Forty-three wild *Arachis* species were screened for resistance to PMV by mechanical inoculation in a screenhouse with PMV-

Table 17. Effect of infection with peanut mottle virus (PMV) on yield of selected groundnut genotypes, ICRISAT Center, postrainy season 1982/83, and rainy season 1983.

	Yield of pods (kg/ha) 1982/83		Yield of pods (kg/ha) 1983	
Genotypes	Not inoculated	Inoculated with PMV	Not inoculated	Inoculated with PMV
FSB 7-2 × EC 76446(292) F_2-B_1-B_1-B_1-B_1-B_1	2690	2120	1930	1580
ICGS 35	3910	3400	2490	2030
NC Ac 2243[1]	2580	1820	-	-
NC Ac 2240	1530	1680	1090	1070
FDRS 4	2550	1860	2380	1850
TMV 2[1]	2430	1370	-	-
Gangapuri[2]	2160	960	1520	1020
SE		±128		±84
CV(%)		20		17

1. Not tested in 1983.
2. PMV susceptible released cultivar.

susceptible TMV 2 as the control. Thirty-seven were infected with PMV (das-ELISA test). Six species (*Arachis* spp 30009, 30081 and 3501, *A. chacoense*, *A. pusilla*, and *Arachis* sp. Manfredi) were not infected despite repeated inoculation.

Mild Mosaic

A disease characterized by mild mosaic symptoms on groundnut foliage was observed at ICRISAT Center in 1978. Incidence was low and the disease has not reappeared. Limited investigations have shown that the causal agent is a virus that is mechanically transmissble but is not transmitted by *Aphis craccivora*, *Frankliniella schultzei*, or *Bemissia tabaci*. Electron microscopy of partially purified virus showed flexuous rods with distinct helical structure. We are investigating the physical properties of the virus.

Insect Pests

Incidence at ICRISAT Center

We monitored the incidence of insect pests and of the thrips-transmitted, bud necrosis disease (BND) on groundnut in unprotected crops in the 1981/82, 1982/83 postrainy and 1982 and 1983 rainy seasons. Leafminer (*Aproaerema modicella*), jassid (*Empoasca kerri*), *Heliothis armigera*, and thrips (*Frankliniella schultzei*) infestations were less than in corresponding seasons of the previous year (Fig. 5, ICRISAT Annual Report 1982 p.191). Infestation by *Scirtothrips dorsalis* thrips was similar in the 1981/82 and 1982/83 postrainy seasons but higher in the 1982 than in the 1981 rainy season. Incidences of BND were similar (55%) in both postrainy seasons but substantially higher in the 1983 than in 1982 rainy season. The low incidence of pests in 1983 probably resulted from heavy rainfall. Rainfall was scant during August 1982 but heavy in November.

Table 18. Effect of thrips on yield of groundnut cv TMV 2, ICRISAT Center, postrainy seasons 1981 to 1983.

Crops exposed to thrips for days	Yield kg/ha			
	Pods		Haulms	
	1981/82	1982/83	1981/82	1982/83
0	1570	1950	3130	2980
15	1580	1810	2870	2700
30	1820	1760	3060	2360
45	1650	1770	2630	2290
60	1760	1600	2400	2040
75	1600	1590	2310	1910
SE	±68	±57	±106	±116
CV (%)	8.2	6.8	7.7	9.7

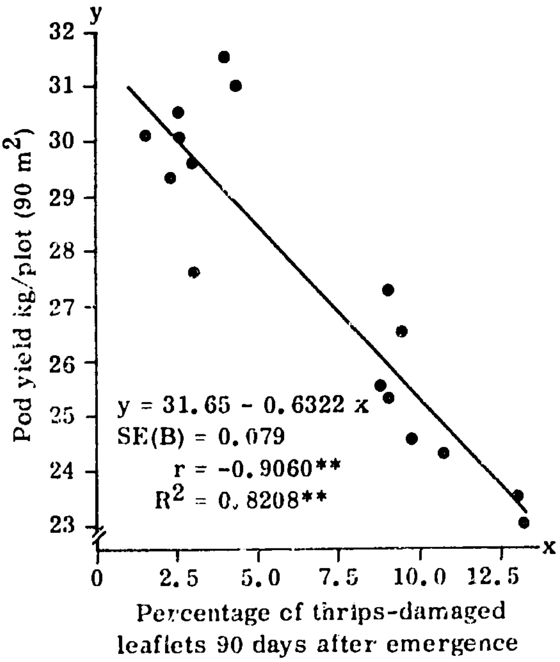


Figure 6. Response of pod yield in groundnut Robut 33-1 to leaflet damage by thrips, ICRISAT Center, postrainy season 1982/83.

Losses from Insects at ICRISAT Center

Trials were conducted during four postrainy seasons, 1979/80 to 1982/83, to determine losses to thrips, *Scirtothrips dorsalis*, with losses the last two years shown in Table 18.

Similar results were obtained in a separate trial with Robut 33-1 in the 1982/83 postrainy season. Crops not protected throughout the growing season yielded 21% less than fully-protected crops. Most of this loss came between 45 and 85 days after sowing. The major pests were *Scirtothrips dorsalis*; yield and thrips were closely related (Fig. 6).

Cultural Practices for Pest Management

Pest incidence in intercropped groundnut. A similar trial to 1982 was conducted during the 1983 rainy season (ICRISAT Annual Report, 1982, p. 193) except that sowing dates were one month later in 1983. Delayed sowing this year resulted in poor intercrop growth. Insect infestation was similar in sole and intercropped groundnut. BND incidence in various intercrops was similar to that in sole groundnut.

Controlling *Lachnosterna fissa* and *Spodoptera litura* with Insecticides

White grubs (*Lachnosterna fissa*), that severely damaged groundnut in the 1982 rainy season (ICRISAT Annual Report, 1982 p. 190) were successfully controlled in 1983 with 0.2% carbaryl applied to host plants of adult beetles. Beetles emerged from the soil at dusk each day and congregated on such plants as *Poinsettia regia* to mate and feed. Spraying the host plants killed large numbers of beetles.

Tobacco caterpillars (*Spodoptera litura*) are difficult to control after the larval stage, but methomyl at 500 or 1000 g ai/ha was effective in field trials against older larvae, as was cypermethrin at 75 or 150 g ai/ha. Control normally depends on applying insecticides while the larvae are young. Monitoring the caterpillars can help time the insecticide application. Male-moth catches in the 1982/83 season in pheromone traps (ICRISAT Annual Report 1982, p. 190) correlated highly with egg masses on crops (r = 0.9505**) (Fig. 7).

Host-Plant Resistance

More than 1200 entries consisting of germplasm lines, breeding lines, and wild *Arachis* species accessions were screened for resistance to various pests and to BND in field, screenhouse, and laboratory tests.

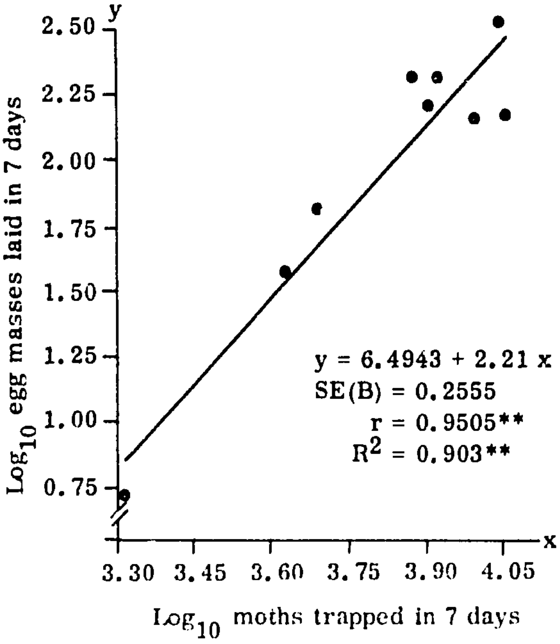


Figure 7. Relationship between numbers of male *Spodoptera litura* moths caught in pheromone traps and numbers of egg masses in surrounding groundnut foliage, ICRISAT Center, postrainy season 1982/83.

Thrips (*Frankliniella schultzei, Scirtothrips dorsalis*). In the 1982/83 postrainy season, 111 promising genotypes were field screened for resistance to *Frankliniella schultzei*, confirming resistance of genotypes previously selected (Table 19).

In the 1983 rainy season, 1000 genotypes were sown in a replicated field trial for preliminary screening. Thrips injury was recorded separately for *S. dorsalis* and *F. schultzei* (ICRISAT Annual Report 1981, p.179). Susceptible genotypes were eliminated; the less susceptible ones are being screened further.

In a laboratory experiment, survival and fecundity of *F. schultzei* and *S. dorsalis* females were recorded on detached leaflets of resistant genotypes in a test at 28°C day time (700 Lux light) and 21°C night time. Survival and fecundity of *S. dorsalis* were lowest on NC Ac 2214 followed in order by NC Ac 2230, NC Ac 2242, and NC Ac 2243. For *F. schultzei* NC Ac 2232 was most resistant. NC Ac 2240, NC Ac 2243, and NC Ac 2242 had fewer nymphs than the susceptible control TMV 2.

Aphids (*Aphis craccivora*). During the 1982 and 1982/83 seasons 500 genotypes were screened in screenhouse trials. Three genotypes were selected from the preliminary trial for further testing at 28°C day time (700 Lux light) and 21°C night time temperatures by releasing five nymphs on each plant. Survival and fecundity of aphids on those three genotypes were lower than on susceptible Robut 33-1. The mean adult survival was 8 days on NC Ac 2214 compared with 14 days on Robut 33-1. Number of nymphs produced at the end of two weeks was 96 on NC Ac 2240, 101 on NC Ac 2230, and 102 on NC Ac 2214 compared with 360 on Robut 33-1. The first three genotypes' leaflets had many long (0.5 mm) hairs on margins, laminae, and midribs.

Leafminer (*Aproaerema modicella*). A total of 2500 genotypes were sown, 2000 at ICRISAT Center, 500 at Raichur (Dharwar district, Karnataka). Leaf miner infestation was too low for screening at ICRISAT. At Raichur, some entries were damaged less than TMV 2 or Robut 33-1 but none was highly resistant. The selected entries are being further tested.

Among the wild species, *A. villosulicarpa* showed high resistance (injury rating 2.0 on a 1 to 9 scale). *A. cardenasii* and K 4 (an interspecific derivative) were moderately resistant (injury rating 3 to 5).

Termites (*Odontotermes spp*). We screened 69 selected genotypes in a termite-infested Alfisol field in a pesticide-free area as described in ICRISAT Annual Report 1982, pp. 197-198). Resistance of several genotypes was confirmed and new sources of resistance were identified (Table 20).

From 1000 genotypes screened in a preliminary trial, several with low pod-scarification were selected for further testing. Of 60 high-yielding, breeding lines, ICG 56 had the least termite damage (1%) followed by ICG 44 (11%), ICG 16 (13%), and ICG 57 (19%). Susceptible ICG 8 had 100% damaged pods.

Bud necrosis disease (BND). We screened 2000 genotypes in a preliminary trial, and 69 in an advanced trial for BND resistance in a pesticide-free Alfisol field. Disease pressure was high, 100% incidence in most lines. Only a few genotypes were selected from the preliminary trial;

Table 19. Extent of damage to thrips *Frankliniella schultzei* in selected groundnut genotypes, ICRISAT Center, postrainy season 1982/83.

Genotypes	Leaflets damaged (%)
NC Ac 2240(T)[1]	4.0
NC Ac 2232(N)[1]	4.4
NC Ac 2243(T)[1]	4.8
NC Ac 2214	4.9
NC Ac 2243(DP)[1]	4.9
Gujarat narrow leaf	5.3
NC Ac 1705	5.4
NC Ac 2242	5.5
NC Ac 2144	5.8
NC Ac 2230	5.8
NC Ac 16940	6.4
NC Ac 2232(Q)[1]	6.6
NC Ac 343	6.8
NC Ac 2277	7.1
K 4	7.2
NC Ac 1741	7.5
NC Ac 2154	7.8
NC Ac 2142	8.2
Controls	
TMV 2[2]	17.8
Ah 60[3]	26.4
SE	±1.96
Mean (111 genotypes)	13.0
CV (%)	26

1. T = Tan testa; DP = Deep purple testa;
N = Normal foliage; Q = Corduroy foliage.
2. Standard control.
3. Susceptible control.

Table 20. Groundnut genotypes showing low pod scarification by *Odontotermes* sp[1], ICRISAT Center, rainy season 1983.

Genotypes	Pods scarified (%)	Severity of scarification[2]
NC Ac 2243(T)	0.0	1.0
NC Ac 2243 (DP)	0.0	1.0
NC Ac 2240 (DP)	0.0	1.0
FESR 386	0.7	1.2
RMP 40	0.8	1.5
C 121	1.1	1.4
NC Ac 17587	1.3	1.3
C 136	1.3	3.0
C 102	1.3	2.6
MK 374	1.8	2.4
NC Ac 17888	1.2	1.6
NC Ac 2242	2.0	1.6
NC Ac 2240(T)	2.3	1.8
PI 414332	2.7	1.3
NC Ac 10033	2.9	1.5
NC Ac 1741	2.9	2.6
C 151	3.1	4.0
69/9	3.3	4.6
Ah 7663	3.5	3.7
NC Ac 2230	3.6	1.3
NC Ac 2232	3.6	3.2
Controls		
NC Ac 343[3]	4.5	4.3
M 13[4]	5.5	6.8
TMV 2[4]	36.0	7.2
Mean 69 entries	7.0	

1. Mean of three replications.
2. Pod scarification rated on a 1-9 scale where 1 = no damage, and 9 = entire shell surface damaged.
3. Resistant control.
4. Susceptible control.

from the advanced trial, however, some previously-selected genotypes had very low BND incidence (Table 21).

In a trial with 62 advanced breeding lines, ICG 37 had the lowest BND incidence (24%); incidences in other lines were ICG 50 (37%), ICG 38 (38%), ICG 32 (40%) and ICG 19 (42%). Robut 33-1 had 68% BND.

Genotypes with low incidence over several seasons are listed in Table 22. From these, high-yielding Robut 33-1, which had about 50% lower BND incidence than TMV 2 at ICRISAT Center, was selected for testing by farmers at Akbarnagar in Nizamabad district. The trial was conducted in collaboration with Andhra Pradesh Agricultural University and the A.P. Department of Agriculture. Robut 33-1 had only 4 ± 2% BND incidence compared with 33 ± 7% in TMV 2.

Breeding for Pest Resistance

Several high-yielding selections that have reached advanced generations differ in suscepti-

Table 21. Groundnut genotypes showing low BND incidence, ICRISAT Center, rainy season 1983.

Genotype	Plants infected with BND (%)	
C 136	5.7	(13.7)[1]
C 121	6.6	(14.8)
NC Ac 2232	7.9	(15.9)
C 107	8.7	(16.3)
Gujarat narrow leaf	9.1	(17.5)
NC Ac 2240	9.6	(17.0)
NC Ac 2243 (DP)	9.7	(18.1)
C 102	10.8	(18.7)
NC Ac 1741	11.6	(19.5)
NC Ac 2242	12.6	(20.1)
C 145-12-P-16	12.8	(20.4)
G0-09	14.2	(21.5)
O-108	14.4	(19.9)
NC Ac 2243(T)	15.0	(22.9)
C 163	15.2	(23.6)
NC Ac 2142	16.7	(24.0)
$F_2P3(1)$ path	18.8	(24.9)
$F_2P4(1)$ path	20.6	(26.1)
NC Ac 343	21.2	(26.9)
Controls		
Robut 33-1[2]	60.6	(52.2)
TMV 2[3]	83.0	(67.4)
SE		±(4.77)
Mean (69 entries)	28.2	(31.24)
CV (%)		(26)

1. Arcsine transformed values in parentheses.
2. Resistant control.
3. Susceptible control.

Table 22. Sources of field resistance to groundnut BND, ICRISAT Center.

Genotype	Seasons tested	BND incidence Mean	BND incidence Range	Mean BND incidence on control TMV 2 (%)
C 136	2	5	4-6	81
C 102	2	9	7-11	81
C 121	2	12	6-18	81
NC Ac 2232	5	7	1-13	45
NC Ac 1741	4	11	7-21	60
NC Ac 2242	5	10	2-14	57
NC Ac 17888	4	14	6-20	51
Gujarat narrow leaf	4	12	9-15	70
NC Ac 343	5	14	3-22	51
Robut 33 1[1]	5	25	11-61	51
M 13[1]	5	19	6-32	51

1. Released Indian cultivars.

Table 23. Some high-yielding, multiple pest resistant groundnut breeding lines, ICRISAT Center, rainy season 1983.

Pedigree	Pod yield kg/ha HI[1]	Pod yield kg/ha LI[2]	Pod yield kg/ha LI[2] pesticide-free area	Yellow foliage (%)	Thrips injury (1 9 scale)	Termite damaged pods (%)	BND affected plants (%)
(Manfredi 68 × NC Ac 343) F_7B_1	2600	1240	283	20	1.2	63	72
[(Gangapuri × MK 374) × (Robut 33-1× NC Ac 2214)] F_7B_1	2580	1210	447	10	1.5	79	44
(Robut 33-1 × NC Ac 343) F_9B_1	2540	1500	425	27	2.2	48	57
(28-206 × NC Ac 10247) F_7B_1	2290	1360	192	25	4.0	36	82
(Robut 33-1 × NC Ac 2214) F_7B_1	2290	1360	303	25	1.2	51	51
(28-206 × NC Ac 2214) F_9B_1	2220	1040	193	32	2.5	63	62
(Robut 33-1 × NC Ac 2214)F_8B_1	2140	840	295	26	1.8	-	54
(Robut 33-1 × NC Ac 2214)F_8B_1	2120	1190	227	21	0.8	-	56
(Robut 33-1 × NC Ac 2214)F_9B_1	1940	1240	410	20	1.7	46	51
Robut 33-1[3]	2110	1150	278	36	2.5	33	68
JL 24[3]	1550	530	7	44	4.0	47	99
J 11[3]	1630	430	57	60	4.0	68	100
NC Ac 343[4]	2020	1200	192	10	1.5	1.0	37
SE	±106.0	±109.0	±32.2	±5.0	±1.0	-	±7.5
CV (%)	11	23	31	-	-	-	-

1. High input, spacing between rows 30 cm, between plants 10 cm.
2. Low input, spacing between rows 60 cm, between plants 15 cm.
3. Nationally released cultivars.
4. Multiple pest and BND resistant high-yielding genotype.

bility to pests and BND. The plant and pod types are agronomically acceptable and pods have normal shelling percentages (Table 23). A selection from the cross (Gangapuri × MK 374) × (Robut 33-1 × NC Ac 2214) has yielded well under high and low inputs at recommended (30×10 cm) and sparse (60×15 cm) spacings. It has high resistance to jassids (*Empoasca kerri*) and thrips, moderate resistance to BND, but high susceptibility to termites. The two nationally released cultivars, J 11, and JL 24, were poor yielders, particularly under low input. Many of the selections outyielded Robut 33-1, and NC Ac 343, a multiple pest-resistant, high-yielding genotype.

Nitrogen Fixation

Response to *Rhizobium* Inoculation

Quality assessment of inoculum. We have compared the plant infection and ELISA methods or quality assessment of peat inoculum. ELISA was found to have considerable advantage in that the number of bacteria on a given strain of the inoculant can be determined within two days. The plant infection procedure takes 25-30 days with the added disadvantage of not being able to identify the specific type of *Rhizobium*.

Table 24. Indirect ELISA and plant-infection methods compared for enumerating rhizobia in soil samples, ICRISAT Center.

Soil samples	Estimated number of rhizobia × 10^4/g dry soil by Indirect ELISA	Estimated number of rhizobia × 10^4/g dry soil by Plant-infection technique
Vertisol	362	92 (23-367)[1]
Alfisol	324	92 (23-367)
Alfisol	229	15 (4-52)
Alfisol	11	5 (1-17)
Vertisol	10	2 (1-8)
Alfisol	30	14 (4-52)
Alfisol	33	43 (10-175)

[1] Confidence limits (95%) for estimations by plant-infection technique are given in parentheses.

Table 25. Effect of inoculum density on nodulation of groundnut cvs Robut 33-1 and ICGS 15, field trial, ICRISAT Center, postrainy season 1982-83.

Inoculum density	Number of nodules[1] per plant	% NC 92 nodules[1]
No inoculum	79	2[2]
10^4	96	14
10^6	76	22
10^8	90	30
SE	±5.6	±4.3

[1] Mean of two cultivars.

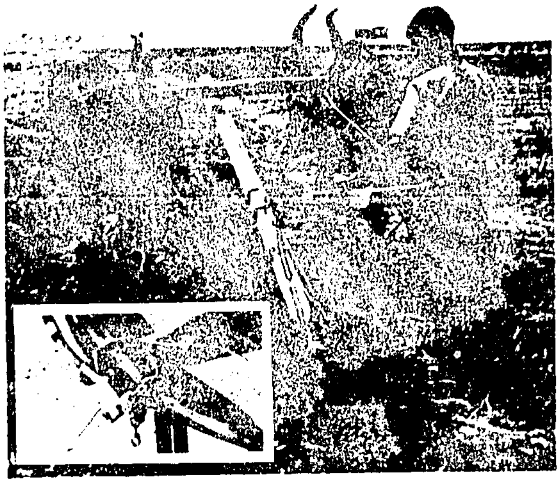
[2] Value excluded from calculating SE.

Enumeration of rhizobia in soil. The plant infection method and indirect ELISA were compared for enumerating rhizobia in soil samples from four fields at ICRISAT Center. Numbers estimated by indirect ELISA fell within confidence limits of the plant-infection method (Table 24).

Inoculum concentration and nodulation. In greenhouse trials, nodulation and N_2-fixation in groundnut increased as *Rhizobium* cells applied to the seed increased (ICRISAT Annual Report 1981, pp. 184-185). In the 1982/83 postrainy season we inoculated seeds of cvs Robut 33-1 and ICGS 15 with several concentrations (0, 10^4, 10^6, and 10^8 rhizobia/seed) of *Rhizobium* strain NC 92 and sowed them in a replicated trial in a field where the native *Rhizobium* population of the top 15 cm of soil ranged from 8×10^2 to 1.7×10^4 cells/g of dry soil. At day 74 after sowing, 5 plants from each plot were examined to determine numbers of nodules formed, and percentage of nodules formed by strain NC 92 was determined by ELISA (Table 25). Inoculation did not significantly increase nodulation. At the generally recommended concentration of 10^4 cells/seed, 14% of the nodules formed included NC 92.

Inoculation methods and use of fungicidal seed dressings. Conventional methods of applying *Rhizobium* inoculum to seed may reduce seedling emergence; we have had better results from applying inoculants as liquids to the soil below seeds at sowing (ICRISAT Annual Reports 181, pp. 184-185, and 1982, pp. 199-200). In the 1982/83 postrainy season we compared nodulation of Robut 33-1 by *Rhizobium* strain NC 92 applied by three methods (direct to seed; liquid applied manually to soil below seed; liquid applied to soil below seed by bullock-drawn seeder), with and without fungicide seed dressing (captan; thiram; Dithane M45®, Bavistin®). Both soil applications gave good nodulation with NC 92, and fungicides had little adverse effect. Direct-seed inoculation was less effective with fungicide applications significantly reducing nodulation (Table 26).

Persistence of inoculated *Rhizobium* strains in soil. In a replicated field trial at ICRISAT Center in the 1982/83 postrainy season, we examined effects of soil inoculation with *Rhizobium* strain NC 92 (in the growing season and in the preceding season) on nodulation of four groundnut cultivars: Robut 33-1, J 11, PI 259747, and ICGS 15. Table 27 shows percentages of plants forming nodules with strain NC 92 both 72 and 116 days after sowing. ELISA was used to type the nodules formed. The results



Applying inoculum as liquid to the soil below seeds with a bullock-drawn seeder: this method has proved more effective than conventional methods of inoculating groundnut seeds with *Rhizobium* strains. Inset shows inoculum flowing into the seeder.

Table 26. Effects of application method and use of fungicide seed dressings on percentage of groundnut nodules formed on cv Robut 33-1 by *Rhizobium* strain NC 92, replicated field trial, ICRISAT Center, postrainy season 1982/83.

Seed dressing fungicide	Percentage of nodules formed by strain NC 92[1]			
	Liquid inoculant to soil		Inoculant applied to seed	No inoculant applied
	Manually	By seeder		
No fungicide	30[2] (27)[3]	27 (22)	22 (20)	4 (2)
captan	28 (23)	17 (9)	7 (4)	3 (1)
thiram	25 (18)	30 (27)	6 (4)	7 (2)
Dithane M45	19 (10)	26 (21)	14 (9)	7 (3)
Bavistin	24 (16)	20 (14)	14 (8)	10 (3)
SE			±2.6 (2.0)	
Mean	25 (19)	24 (19)	13 (9)	6 (2)

1. Nodules typed by ELISA at 60 days after sowing.
2. Data after angular transformation.
3. Original data.

Table 27. Persistence of *Rhizobium* strain NC 92 inoculum in soil; percentage of groundut cultivars forming nodules after different inoculations, ICRISAT Center, postrainy season 1982/83.

Inoculation with NC 92		Days after sowing	Cultivars forming nodules (%)					
1982	1982/83	(DAS)	Robut 33-1	J 11	PI 259747	ICGS 15	Mean	SE
–	–	72	7[1]	5[1]	10[1]	6[1]	7	
		116	6	2	12	5	6	
–	+	72	22	29	30	25	26	
		116	27	33	24	15	25	±3.3 (72 DAS)
+	–	72	22	23	37	19	25	±3.7 (116 DAS)
		116	35	28	42	25	32	
+	+	72	34	36	53	37	40	
		116	51	59	57	46	53	
	SE			±6.6	(72 DAS)			
	SE			±7.5	(116 DAS)			

1. Values excluded from calculations of SE.

indicate that it may not be necessary to inoculate a field more than once with a specific strain.

Nitrogen Fertilizer Studies

During the 1982 rainy and 1982/83 postrainy seasons, we observed that response to nitrogen differed among groundnut cultivars. Fertilizer nitrogen (urea) did not influence total N uptake of J 11, PI 259747, but increased that of ICGS 15 and Robut 33-1 (Table 28). Nitrogen fertilization increased nitrate uptake (r = 0.94) but decreased nitrogen fixation (r = 0.92) primarily by reducing the number of nodules.

We are now attempting to quantify nitrogen derived from different sources. During the 1982/83 postrainy season we studied nitrate reductase in one nonnodulating line identified at ICRISAT, and two nodulating genotypes, PI 259747 and ICGS 15. Nitrogen increased nitrate uptake and leaf-nitrate reductase activity in all cultivars. The nonnodulating groundnut genotype's nitrate uptake and leaf nitrate reductase activity were no higher than those of the nodulating genotypes.

Plant Improvement

Breeding for High Yield and Quality

Postrainy Season 1982/83

Generation advance and selection. We sowed 1052 F_2 to F_{11} generation-selected, bulk populations in irrigated Alfisols with high nutrient input for generation advance and selection for yield and other desirable agronomic traits. Several high yielding bulks were made.

Yield trials at ICRISAT Center. The 11 yield trials during the season were given fertilizer at high rates and protected against pests. Selections in F_{10} and F_{12} generations were evaluated, against three controls. Pod yields of the seven best selections are given in Table 29. Selection Robut 33-1-1-5-8B_1 produced the highest pod yield (7040 kg/ha) followed by H3/7, a derivative from an interspecific cross (6800 kg/ha).

Sixty-one ICGS lines were further evaluated against three controls. Several produced more

Table 28. Effect of nitrogen fertilization on total nitrogen uptake (kg/ha) by groundnut cultivars at final harvest, ICRISAT Center, rainy season 1982.

	Nitrogen fertilizer applied (kg/ha)				
Cultivar	0	200	400	Mean	SE
	Nitrogen uptake by final harvest				
J 11	116	123	120	120	
Robut 33-1	130	158	145	145	±6.1
ICGS 15	133	152	149	145	
PI 259747	110	111	113	111	
SE		±9.3			
Mean	123	136	132		
SE		±4.3			

than 7000 kg/ha of pods (Table 30). ICGS 22 gave the highest yield (7610 kg/ha).

Twenty-four spanish bunch selections were evaluated against three controls in an initial trial. Pod yields of the 9 best-yielding selections are presented in Table 31. Goldin I × Robut

Table 29. Pod yields of seven groundnut selections ICRISAT Center, postrainy season 1982/83.

Pedigree	Pod yield (kg/ha)
Robut 33-1-1-5-8B_1	7040
H3/7	6800
(Manfredi × NC Ac 2750)$F_{12}B_1$	6570
(USA 20 × TMV 10)$F_{12}B_1$	6540
Robut 33-1-13-6-8B_1	6540
Robut 33-1-12-10-8B_1	6440
(X14-X-X-1-B × Goldin I)-$F_{12}B_1$	6420
Controls[1]	
Robut 33-1	5030
J 11	4930
JL 24	4400
SE	±496
Trial mean (149 cvs)	5100
CV (%)	18

1. High-yielding released cultivars.

Table 30. Yields of eight selected groundnut ICGS lines, ICRISAT Center, postrainy season 1982/83.

Identity	Pod yield (kg/ha)
ICGS 22	7610
ICGS 36	7370
ICGS 30	7340
ICGS 61	7320
ICGS 37	7230
ICGS 27	7190
ICGS 20	7130
ICGS 21	7040
Controls[1]	
Robut 33-1	6180
J 11	5440
JL 24	3860
SE	±297
Trial mean (64 cvs)	6125
CV (%)	10

1. High-yielding released cultivars.

Table 31. Yields of selected spanish bunch groundnut selections in Initial Yield Trial, ICRISAT Center, postrainy season 1982/83.

Pedigree	Pod yield (kg/ha)
(Goldin I × Robut 33-1)-$F_{11}B_1$	7190
(Florigiant × Robut 33-1)-$F_{10}B_1$	6760
(28-206 × Chico)-$F_{10}B_2$	6750
(X14-4-B-19-B × NC Ac 316)-$F_{10}B_1$	6610
(Shulamit × Chico)-$F_{11}B_1$	6590
(Starr × MH 2)-$F_{10}B_2$	6500
(Sm-5 × Robut 33-1)-$F_{10}B_1$	6480
(28-206 × Robut 33-1)-$F_{10}B_2$	6440
(Florigiant × Chico)-$F_{12}B_1$	6350
Controls[1]	
J 11	5690
JL 24	4620
SE	±229
Trial mean	6130
CV (%)	7

1. High-yielding released cultivars.

33-1-$F_{11}B_1$ was first in pod yield (7188 kg/ha).

Fifteen spanish bunch and 16 virginia bunch F_{11} selections were separately evaluated for yield potential. Pod yields of the best 4 of each are given in Table 32.

Rainy Season 1983

Generation advance and selection. From 1020 F_2 to F_{12} generation selected bulks grown, we selected 440 promising bulks for further testing, also 200 high-yielding bulks from rust and leaf spot-susceptible, segregating populations of interspecific derivatives.

Table 32. Yields of selected spanish and virginia bunch groundnut selections in F_{11} Trial, ICRISAT Center, postrainy season 1982/83.

Pedigree	Pod yield (kg/ha)
Spanish bunch trial	
(JH 89 × Robut 33-1)-$F_{11}B_1$	6350
(Shulamit × Chico)-$F_{11}B_1$	6330
(Sm5 × Robut 33-1)-$F_{11}B_1$	6200
(JH 89 × Robut 33-1)-$F_{11}B_2$	6110
Controls[1]	
J 11	5410
JL 24	4960
SE	±238
Trial mean	5790
CV(%)	8
Virginia bunch trial	
(Robut 33-1 × NC Ac 316)-$F_{11}B_1$	6630
(Robut 33-1 × NC Ac 2821)-$F_{11}B_1$	6620
(NC Ac 1107 × Robut 33-1)-$F_{11}B_1$	6590
(Robut 33-1 × M 13)-$F_{11}B_1$	6590
Control[1]	
Robut 33-1	6070
SE	±174
Trial mean	6280
CV (%)	5

[1] High-yielding released cultivars.

Yield trials at ICRISAT Center. Three hundred and forty advanced generation selections were evaluated against three controls, and 61 stable breeding lines (ICGS) and three controls were further yield-tested under high and low inputs in 8 × 8 lattice field trials. Pod yields of the 10 highest-yielding selections from each trial are given in Table 33. ICGS 50, a wild species derivative from the cross *A. hypogaea* × *A. cardenasii*. gave the highest yield under high input. Under low input ICGS 35 gave the highest pod yield (1690 kg/ha) followed by ICGS 11 and ICGS 6, each significantly outyielding both controls.

We evaluated 78 F_{10} and F_{11} generation selections under high and low inputs. Pod yields of the 5 best from each trial are given in Table 34.

Four selections outyielded Robut 33-1 and JL 24 under high input and 11 more outyielded Robut 33-1; 5 outyielded all 3 controls under low input, and 39 more outyielded J 11 and JL 24. Robut 33-1-1-59B_1 performed well under both high and low input conditions.

Yield trials at Bhavanisagar, Dharwar, and Anantapur. Two rainfed yield trials were conducted at three locations in India. Table 35 lists the 10 highest-yielding selections at each location. At Bhavanisagar, 24 outyielded J 11 and JL 24. At Dharwar, 3 selections outyielded the 3 controls; 13 others outyielded Robut 33-1 and 4 of them also outyielded JL 24. At Anantapur no selection was superior to JL 24.

Photoperiod Adaptation

Studies of photoperiod responses of groundnut cultivars were conducted in collaboration with the University of Bonn, Federal Republic of Germany, to establish the significance of day-length on groundnuts' adaptability to different latitudes. Some photoperiod sensitive cultivars yielded twice as much in short (12 hr) days as in the longest (16 hr) days where groundnuts are cultivated. Growth regulator Kylar partially reversed the long-day effects (Table 36), indicating that measurement of endogenous growth regulating substances may allow effective identification of photosensitive material.

Table 33. Pod yields of 20 selected ICGS groundnut lines and 2 controls, ICRISAT Center, rainy season 1983.

	High input			Low input	
Identity	Pod yield (kg/ha)	Shelling %	Identity	Pod yield (kg/ha)	Shelling %
ICGS 50	3800	71	ICGS 35	1690	60
ICGS 30	3580	68	ICGS 11	1620	76
ICGS 1	3580	70	ICGS 6	1620	68
ICGS 33	3500	64	ICGS 1	1570	76
ICGS 12	3430	64	ICGS 45	1560	68
ICGS 27	3400	72	ICGS 34	1540	64
ICGS 58	3400	63	ICGS 17	1540	56
ICGS 11	3370	72	ICGS 20	1530	80
ICGS 32	3330	67	ICGS 61	1520	64
ICGS 61	3330	74	ICGS 30	1510	68
Controls			Controls		
JL 24	3070	74	JL 24	590	56
Robut 33-1	2810	70	Robut 33-1	1321	76
SE	±180		SE	±89	-
CV (%)	10		CV (%)	12	-

Earliness and Dormancy

Dormancy in early maturing lines. We completed our study of methods to screen for dormancy by investigating how pod maturity affects the expression of dormancy. Twelve early-maturing genotypes selected as dormant by the method developed at ICRISAT were harvested at weekly intervals from 109 to 130 days days after sowing. Observations of field sprouting were made at each harvest and pod samples were tested for seed germination after curing 17 to 20 days. Lines found dormant in the laboratory test had negligible field sprouting. Tests to observe

Table 34. Pod yields of 10 groundnut selections, and 3 controls, ICRISAT Center, rainy season 1983.

High input			Low input		
Pedigree	Pod yield (kg/ha)	Shelling %	Pedigree	Pod yield (kg/ha)	Shelling %
(Spancross × Tifspan)-$F_{11}B_1$	3210	52	Robut 33-1-1-5-F_9B_1	1440	64
Robut 33-1-1-5-9B_1	3190	60	Robut 33-1-27-20-F_9B_1	1320	64
(GAUG-1 × NC Ac 529)-$F_{11}B_1$	3150	60	Robut 33-1-11-15-F_9B_1	1300	64
(Starr × TG 16)-$F_{11}B_1$	3110	46	(NC Ac 2462 × M 13)-$F_{11}B_1$	1250	54
(NC Ac 17113 × Spancross)-$F_{10}B_1$	3090	66	(NC Ac 2462 × M 13)-$F_{11}B_1$	1170	52
Controls			Controls		
Robut 33-1	2440	62	Robut 33-1	1010	60
J 11	2900	68	J 11	380	48
JL 24	2650	66	JL 24	370	44
SE	±162		SE	±57	
Trial mean	2900		Trial mean	650	
CV (%)	10		CV (%)	15	

Table 35. Pod yield of ten best-yielding groundnut selections at three Indian locations, rainy season 1983.

Pedigree	Pod yield (kg/ha)	Pedigree	Pod yield (kg/ha)	Pedigree	Pod yield (kg/ha)
Bhavanisagar		Dharwar		Anantapur	
(Robut 33-1 × NC Ac 2821)-$F_{12}B_1$	3320	(M 13 × Robut 33-1)-$F_{12}B_2$	4130	(Robut 33-1 × NC Ac 316)-$F_{12}B_1$	2050
(Robut 33-1-13-6-9B_1)	3240	(TMV 10 × Robut 33-1)-$F_{11}B_1$	4020	(Spancross × NC 268)-$F_{12}B_1$	1920
(TMV 7 × Robut 33-1)-$F_{12}B_1$	3170	(Manfredi × M 13)-$F_{13}B_1$	3920	(MK 374 × Robut 33-1)-$F_{12}B_1$	1910
(Manfredi × M 13)-$F_{12}B_1$	3120	(USA 20 × TMV 10)-$F_{13}B_1$	3670	(72-R × Robut 33-1)-$F_{12}B_1$	1910
(Robut 33-1 × M 13)-$F_{12}B_1$	3100	(NC Ac 1107 × Robut 33-1)-$F_{12}B_1$	3640	Robut 33-1-11-15-9B_1	1880
(Dh 3-20 × USA 20)-$F_{13}B_1$	3080	(JH 335 × Robut 33-1)-$F_{12}B_1$	3570	(Sm5 × Ah 6279)-$F_{10}B_1$	1860
(TMV 10 × Robut 33-1)-$F_{11}B_1$	3070	H 3-7	3480	(X14-4-B_1-19-B × NC Ac 316)-$F_{11}B_1$	1840
(Shulamit × Chico)-$F_{12}B_1$	3050	(Shulamit × Chico)-$F_{12}B_1$	3240	(MK 374 × Robut 33-1)-$F_{12}B_1$	1840
(Robut 33-1-1-1-9B_1)	3050	(Robut 33-1 × NC Ac 2821)-$F_{13}B_1$	3220	(Sm5 × Robut 33-1)-$F_{11}B_1$	1840
(Robut 33-1 × NC Ac 2698)-$F_{13}B_1$	3030	(M 13 × Robut 33-1)-$F_{12}B_1$	3210	Robut 33-1-27-20-9B_1	1830
Controls		Controls		Controls	
J 11	2250	J 11	2900	J 11	1760
JL 24	2190	JL 24	2620	JL 24	1920
Robut 33-1	2820	Robut 33-1	1980	Robut 33-1	1730
SE	±202	SE	±298	SE	±100
Mean	2644	Mean	2448	Mean	1551
CV (%)	13	CV (%)	21	CV (%)	11

the breakdown of dormancy in selected lines showed that most were dormant for 24 days, and that dormancy usually was broken 60 days after harvest.

Breeding for earliness and seed dormancy. From a field trial with 265 germplasm lines at ICRISAT Center in the 1983 rainy season, 76 single plant selections were made from 26 germplasm lines that matured within 85 days of sowing.

One hundred and twenty-two new crosses were made between previously-identified sources of earliness (ICRISAT Annual Report 1982, p. 213) and several cultivars with large seeds.

Twelve lines identified as having limited seed dormancy were used in a crossing program to combine earliness and seed dormancy.

Chico and other sources of earliness were treated with physical and chemical mutagens to generate new variability within the existing genetic base.

Using Wild Species

Incorporating desirable genes from wild species into *A. hypogaea* continued, by backcrossing selected resistant plants to *A. hypogaea*, or by selfing advanced selections. Advanced selections for foliar-disease resistance were grown at two locations to screen for rust and late leaf-spot

Table 36. Mean kernel weights (g/m^2) for six cultivars of groundnuts as influenced by day length (DL) and Kylar, ICRISAT Center, postrainy season 1982/83.

Cultivar	Day length	Kylar -	Kylar +	Kylar Mean	Cultivar mean
Robut 33-1	SD[1]	157	201	179	
	LD[2]	174	207	191	185
S 7-2-13	SD	122	150	136	
	LD	72	121	96	116
M 13	SD	111	78	95	
	LD	43	70	56	75
TMV 2	SD	160	144	152	
	LD	193	164	178	165
Krapovickas	SD	99	112	106	
St. 16	LD	68	93	81	93
NC Ac 17090	SD	169	164	166	
	LD	115	118	117	141
SE (DL × Kylar)		±19.31		±13.16	±9.99
Mean	SD	136	142	139	
	LD	110	129	120	
SE (Kylar)		±6.34		±2.62	
Mean		123.4	135.3		
SE		±5.76			

1. SD = short day, 12 hr.
2. LD = long day, 16 hr.

resistance. New *Arachis* species germplasm has been screened, studied cytogenetically, and incorporated into crossing programs to transfer genes by various routes.

By altering the hormones used and the time of application, we improved our techniques for inducing pegs and pods in crosses between species previously considered incompatible. Improvements in culture techniques and media used enable us to stimulate more ovules from these crosses to grow in vitro.

Producing Interspecific Derivatives

Emphasis in cytogenetics is now moving to using the new accessions, which may be valuable in broadening the genetic base of resistance, even if resistance genes are available in *A. hypogaea*. The new accessions may be the only sources of resistance to some pests and diseases. After being cleared through Plant Quarantine, they were screened for desirable characters and analyzed cytologically to help plan the best utilization routes (Table 37).

Attention was paid to the marker chromosomes of section *Arachis*, the characteristic small chromosome of *A. correntina* and related A genome species, and the large chromosome of *A. batizocoi*, the one known B genome species. Also recorded were the position of the nucleolar organizer, arm ratios of the chromosomes, and the number of different types of chromosome, from median with the centromere in the center (arm ratio 1.0) to subterminal, with the centro-

Table 37. Somatic complements of some new accessions of *Arachis* and their probable sectional affinities, ICRISAT Center, 1983.

ICG no.	Coll. no.	2n	Range of L/S arm ratio	Karyotypic formula	Marker chromosome[1] A	Marker chromosome[1] B	NO[2] region	Probable section
8192	30008	20	1.00-1.44	4M+5Sm+1SmSat[3]	P	N	Proximal	*Arachis*
8954	30035	20	1.00-1.40	3M+6Sm+1SmSat	P	N	Proximal	*Arachis*
8955	30036	20	1.00-1.57	3M+6Sm+1SmSat	P	N	Proximal	*Arachis*
8195	30060	20	1.00-1.80	4M+5Sm+1SmSat	P	N	Extreme Proximal	*Arachis*
8197	30062	40	1.00-1.45	6M+13Sm+1MSat	P	P	Proximal	*Arachis*
8198	30063	40	1.00-1.50	6M+13Sm+1MSat	P	P	Proximal	*Arachis*
-	30070	20	1.00-1.56	4M+5Sm+1SmSat	P	N	Proximal	*Arachis*
8957	30074	20	1.00-1.32	3M+6SM+1SmSat	P	N	Proximal	*Arachis*
8205	30075	20	1.00-1.46	2M+7Sm+1SmSat	P	N	Proximal	*Arachis*
8206	30076	20	1.00-1.44	2M+7Sm+1SmSat	N	P	Proximal	*Arachis*
8961	30097	20	1.00-1.50	2M+7Sm+1SmSat	N	P	Proximal	*Arachis*
8960	30092	20	1.00-1.40	1M+8Sm+1SmSat	N	P	Proximal	*Arachis*
-	35001	20	1.00-1.27	5M+4Sm+1SmSat	P	N	Proximal	*Arachis*
8945	30003	20	1.00-2.66	6M+1Sm+2St+1SmSat	N	N	Distal	Erectoides
8191	30007	20	1.00-2.75	4M+4Sm+1St+1SmSat	N	N	Distal	Erectoides
8946	30009	20	1.07-2.70	2M+5Sm+2St+1SmSat	N	N	Distal	Erectoides
8948	30016	20	1.00-2.66	1M+7Sm+1St+1SmSat	N	N	Proximal	Erectoides
8963	30109	20	1.04-1.61	1M+8Sm+1SmSat	N	N	Distal	Erectoides
8215	30126	20	1.00-2.15	5M+4SM+1ST	N	N	-	Erectoides
8973	30134	20	1.05-1.69	3M+7Sm	N	N	-	Erectoides
3958	30080	20	1.05-2.10	2M+6Sm+1St+1SmSat	N	N	Proximal	Unknown

1. Marker chromosome = Presence (P) or nonpresence (N) of the marker chromosomes of the two genomes (A and B) in section *Arachis*.
2. NO = Nucleolar organiser.
3. M = Chromosomes with median centromere; Sm = Chromosomes with submedian centromere; Sat = Satellite; St = Chromosomes with arm ratio more than 2.0.

mere near one end (maximum arm ratio observed, 2.7). The short A chromosome of 30035 and of 30036 was longer than in *A. correntina*, but similar to the A chromosome of *A. cardenasii*. The nucleolar organizer chromosomes of 30070 and 30074 are similar to that of *A. duranensis*. The nucleolar organizer chromosomes of 30076, 30097, and 30092 was similar to that of *A. batizocoi*, so they may be new accessions with the B genome.

The identities and relationships of the new accessions are unknown, so we attempted crossing selected accessions with two diploid species (one A genome species and one B genome species) and with two subspecies of *A. hypogaea* to assess their crossability, genomic relationship, and potentials as sources of desired genes (Tables 38 and 39). Each of the four selected accessions could be crossed, as male parent, with *A. batizocoi* (B genome) but only three were successful as female parent. We have attempted crosses with the A genome species between only three new accessions and *A. cardenasii* as female parent. None produced seeds. All crosses with *A. hypogaea* produced pods. Pods were produced for the first time from the cross *A. chacoense* × *A. cardenasii* treated with growth hormones. All crosses with *A. hypogaea* produced pods (Table 39).

The backcross progenies (ICRISAT Annual Report 1982 p. 216, 217) were further backcrossed or advanced by selfing, and 37 additional fertile tetraploid derivatives were produced for further resistance screening. By the end of the 1983 rainy season, 74 fertile and cytologically stable tetraploids had been selected from various species by different routes (Table 40). Emphasis during early years was on the hexaploid route to use three species for leaf spot resistance; later emphasis has been on breeding at the tetraploid level, especially using amphiploids to combine desirable characters from two species. A total of 29 amphiploid combinations have been produced; 6 species have been successful as female parents, 8 as male parents (Table 40). From their progenies, 598 single plants were selected for leaf spot resistance, and 302 had less than average thrips damage.

Table 39. Crossability of *A. hypogaea* with four new diploid accessions, ICRISAT Center, 1983.

A. hypogaea × diploid taxa	Pollinations (No)	Pods (No)	Pods/Pollination (%)
A. sp 30007	70	19[1]	27
A. sp 30011	87	41	47
A. sp 30017[2]	31	3	10
A. sp 30035	23	1	4

1. All with poorly developed seed.
2. Crossed with one cultivar only.

Material Supplied to Breeders

ICRISAT groundnut breeders have selected material from among progenies of wild species derivatives, at or near the tetraploid level, to incorporate in breeding programs (Table 41). Seven wild species, alone or in combination, have produced useful derivatives after crossing with *A. hypogaea*. Single plants and bulks were

Table 38. Crossability of four new diploid accessions with two diploid species of section *Arachis*, ICRISAT Center, 1983.

♂ Parent / ♀ Parent	30035			30017			30011			30007			*A. chacoense*		
	a[1]	b	c	a	b	c	a	b	c	a	b	c	a	b	c
A. batizocoi	39	22	56	31	18	58	36	24	67	29	1	3	44	19	43
Reciprocal	31	0	0	87	13	15	91	8	9	69	7	10	46	0	0
A. cardenasii	74	0	0	60	0	0	-	-	-	60	0	0	77	0	0

1. a = number of pollinations; b = number of pods produced; c = pods/pollination %.

Table 40. Fertile tetraploid progenies obtained from *A. hypogaea* × wild species crosses by indicated routes, ICRISAT Center.

	Route				
		Amphiploid			
Species	Hexaploid	f[1]	m[2]	Autotetraploid	Triploid
A. villosa		6	3	1	
A. correntina		9	1	1	
A. chacoense	7		8		2
A. cardenasii	12		2		12
A. sp HLK 410	3	3	3	1	
A. duranensis		5	4		
A. sp GKP 10038		1	2	1	
A. batizocoi		5	6	5	
Totals	22	29		9	14

1. Listed under female parent.
2. Listed under male parent.

selected for yield and rust, leaf spot, and pest resistance.

From the advanced selections, two *A. hypogaea* × *A. cardenasii* selections, CS 9 [ICG(CG.FDRS)-17] and CS 11 [ICG(CG.FDRS)-18] have been entered in the AICORPO Foliar Disease Resistance Varietal Trial, and another high-yielding segregate from the same combination, ICGS 50, in the AICORPO yield trial. CS 9 and CS 11 showed the lowest incidence of late leaf spot in the foliar disease trial at ICRISAT Center in 1983 (Table 8). CS 9 gave the highest yield in the trial under both high and low inputs.

Table 41. Number and origin of groundnut selections made by breeders from wild species derivatives, ICRISAT Center, 1983.

Species used as parents	Selections (No).
A. cardenasii	245
A. chacoense	58
A. sp 10038	29
A. villosa and *A.* sp 10038	20
A. batizocoi	16
A. duranensis and *A. chacoense*	15
A. batizocoi and *A.* sp 10038	8
A. correntina and *A. villosa*	4
A. villosa	2
A. correntina, A. chacoense and *A. cardenasii*	1

Barriers to Hybridization

Studies continued using growth hormones to stimulate peg and pod formation in intersectional crosses in *Arachis*, which produce few pods by conventional crossing. Pegs induced by gibberellin (ICRISAT Annual Report 1982, p. 222) were subsequently treated with indole acetic acid (IAA) or naphthalene acetic acid (NAA). NAA effectively induced pod formation.

Ovule and Embryo Culture

We have cultured immature ovules and embryos from pods from incompatible crosses, and found filter paper bridges (Fig. 8) with Murashige and Skoog's liquid media with 5% sucrose and 0.1 to 0.2 mg/liter of kinetin better than agar media for survival and growth of cultured ovules. Agar media with 0.5 mg/liter benzyl amino purine (BAP) and 0.5 to 2.0 mg/liter of NAA stimulates callus formation from ovules. Ovules from crosses of *A. hypogaea* MK 374, TMV 2, or M 13 with rhizomatous species grew more often in culture than those from crosses using Robut 33-1.

Figure 8. Embryos emerging from cultured immature ovules on filter paper bridge from the cross *Arachis hypogaea* cv TMV 2 × *Arachis* species PI 276233.

International Cooperation

Cooperation with AICORPO

Coordinated Yield Trials

ICRISAT Center trials. During the 1983 rainy season seven yield trials sponsored by AICORPO were conducted on Alfisols at ICRISAT Center without supplementary irrigation or protection from pests. Heavy BND, late and early leaf spots, and rust incidence all reduced yields.

In the initial evaluation trial with spanish bunch cultivars six ICRISAT lines were included; two, ICGS 35-1 (1690 kg/ha) and ICGS 44-1 (1610 kg/ha), outyielded the best control, Robut 33-1 (1360 kg/ha). In the trial with virginia bunch cultivars, five ICRISAT lines were tested and three NFG 5 (1610 kg/ha), CGC 6 (1570 kg/ha) and ICGS 56 (1090 kg/ha), yielded more than Robut 33-1 (800 kg/ha). Both NFG 5 and CGC 6 are selections made by cooperators from ICRISAT breeding material.

In the coordinated varietal trial with spanish bunch types, CGC 4018, a rust-resistant selection by a cooperator from ICRISAT breeding material, ranked highest in yield (1140 kg/ha). In the virginia bunch trial, three ICRISAT lines were tested and ICGS 6 yielded more (1030 kg/ha) than Robut 33-1 (720 kg/ha).

Multilocation Trials

Rainy season trials. During the 1982 rainy season, 20 ICGS lines were tested in various AICORPO trials at 19 locations representative of the 6 groundnut zones of India. Eleven lines were promoted to advanced tests in different zones. Three new virginia bunch types, ICGS 50, 52, and 56, and four new spanish bunch types, ICGS 35-1, 44-1, 51, and 57, were entered in advanced tests during the 1983 rainy season.

Some ICGS selections performed well in the Initial Evaluation Trials (IET) especially in the northern zone (Table 42). Three virginia bunch selections ICGS 4, 5, and 6, and one spanish bunch selection, ICGS 1, were promoted to the National Evaluation Trial (NET) in the 1983 rainy season.

Postrainy season yield trials. In the 1982/83 season, the AICORPO/ICRISAT postrainy season yield trials were conducted at five locations. Of 18 ICRISAT entries tested, ICGS 21 and 44 (for Coordinated Varietal Trials (CVT), and ICGS 6, ICGS 19 and 37 (for National Evaluation Trials (NET) were recommended for testing in the 1983/84 postrainy season. In the Final Evaluation Trial (FET) at 14 locations, four ICRISAT selections were included. Yield data from the central and peninsular zones are given in Table 43. Based on consistent good performance for three years, ICGS 11 was promoted to mini-kit trials in central peninsular zones of India for the 1983/84 postrainy season.

Foliar disease resistance. During the 1982 rainy season, 10 germplasm and breeding lines with resistance to rust and late leaf spot diseases and three susceptible controls, JL 24, J 11, and a local cultivar were evaluated in a Foliar Diseases Resistance Varietal Trial at seven locations in India. Disease pressure varied among locations and no uniform disease scoring method was used. The best resistant lines gave 6 times higher yields than the best susceptible control at ICRISAT Center, where disease pressure was high (Table 44).

***Rhizobium* inoculation trials.** During the 1981 and 1982 rainy seasons inoculation with the *Rhizobium* strain NC 92 increased yields of Robut 33-1 at several AICORPO locations

Table 42. Yields of ICRISAT groundnut entries in the AICORPO trials in the northern zone, India, rainy season 1982.

Identity	Dholi (rainfed)	Kanke (rainfed)	Hissar (irrigated)	Ludhiana (irrigated)	Mainpuri (irrigated)	Mean
IET (VB)[1]						
ICGS 46	1480(3)[3]	1290(5)	4530(3)	3020(4)	2260(2)	2516
ICGS 47	1370(4)	770(10)	4640(2)	3510(1)	2200(3)	2498
ICGS 49	1310(6)	1030(7)	3960(6)	3400(2)	2200(3)	2380
ICGS 48	2110(2)	1440(4)	4150(4)	2890(5)	1160(6)	2350
ICGS 18	980(8)	960(8)	4810(1)	3070(3)	1620(4)	2288
ICGS 20	950(9)	930(9)	3640(7)	2890(5)	1450(5)	1972
Control						
TMV 10	1210(7)	1160(6)	3240(9)	1520(9)	750(7)	1576
SE	±185	±125	±193	±263	±273	
Trial mean	1440	1350	3970	2730	1680	
CV (%)	23	16	12	19	23	
IET (SB)[2]						
ICGS 21	-	1610(2)	4790(1)	2210(4)	-	2870
ICGS 11	-	870(15)	4520(3)	2810(2)	-	2733
ICGS 26	-	1250(6)	4220(8)	2680(3)	-	2717
ICGS 30	-	1650(1)	4760(2)	1700(16)	-	2703
ICGS 2	-	1220(7)	4460(4)	1980(6)	-	2553
ICGS 3	-	1030(13)	4340(5)	1790(12)	-	2387
Controls						
J 11	-	1070(12)	3810(10)	1780(14)	-	2220
JL 24	-	1480(4)	3270(16)	1930(8)	-	2227
SE	-	±109	±287	±117		
Trial mean	-	1080	3910	1920		
CV (%)	-	20	13	18		

1. IET(VB) = Initial Evaluation Trial, virginia bunch types.
2. IET(SB) = Initial Evaluation Trial, spanish bunch types.
3. Figures in parentheses are yield ranks.

Table 43. Yields (kg/ha) of ICRISAT groundnut entries in the Final Evaluation Trial (FET), postrainy season 1982/83.

	Central zone				Peninsular zone						
	Akola	Pal	Parbhani	Mean	Bagalkot	Dharwar	Digraj	Garikapadu	Karimnagar	Raichur	Mean
ICGS 11	2200	2460	4250	2970	2590	2660	4100	3890	2100	3130	3078
ICGS 6		2160	3690	2925	3720		3470	220	280	2380	3214
ICGS 12	2240	2370	3170	2594	1990	2700	4050	1110	1750	2380	2330
ICGS 15	2190	2220	2430	2280	3520	2600	3080	2000	2190	2600	2665
Control											
J 11	1670	2520	2830	2340		1910	2310	2160	2410	2250	2208
SE	±92	±237	±325		±379	±406	±214	±160	±81	±369	
Trial mean	1790	2180	3010		3080	2450	2620	2990	2080	2350	
CV (%)	10	22	15	24	20	16	10	8	22		

(Table 45), but not at Tirupati or Kadiri. Soil analyses revealed high manganese content (56 ppm) in fields at Tirupati which may interfere with nodule activity.

Distribution of breeding material. Besides supplying seeds for various ICRISAT entries in the AICORPO trials, we supplied 308 breeding lines and parental lines to 19 cooperators in India and further 843 lines to 16 other countries.

From the breeding material supplied by ICRISAT, cooperators in India have developed use-

Table 44. Groundnut Foliar Diseases Resistance Varietal (AICORPO) Trial, rainy season 1982.

	Yield (kg/ha)							
Entry	Jalgaon	Dharwar	Kadiri	ICRISAT	Tirupati	Aliyarnagar	Vriddhachalam	Mean
ICG 1697		2750	3060	900	2190	1620	1690	2033
CGC 4018	1080	2300	2790	2370	1750	1650	1530	1922
CGC 4007	890	2490	1660	2000	1940	1410	1230	1645
ICG (FDRS)-1	800	1550	2340	1420	1790	1410	1450	1533
ICG 7882	410	2670	2420	1210	1550	1380	1100	1535
ICG (FDRS)-4	380	2730	1770	1920	1610	1320	1430	1509
ICG (FDRS)-2	580	1700	2180	1260	1680	1480	1410	1470
ICG 7898	80	1240	2360	940	1550	1700	1260	1341
CGC 4002	1760	1610	1410	1080	-	480	710	1176
ICG (FDRS)-3	250	1980	970	1140	860	1200	1320	1102
Controls								
JL 24[1]	2560	2360	3610	240	1990	1250	-	2000
J 11[1]	1120	2390	3060	220	1980	520	1240	1500
Local cultivar	-	1890	2240	360	2040	770	1340	-
SE	±48	±596	±127	±102	±98	±86	±31	-
Trial mean	810	2160	2320	1160	1730	1210	1310	-
CV (%)	11	34	11	18	11	71	20	-

[1] Susceptible cultivars.

Groundnut selection VG 19 being multiplied on a large scale for trials in Tamil Nadu, India. That selection is from segregating material supplied by ICRISAT.

Table 45. Pod yield response (kg/ha) of groundnut Robut 33-1 to *Rhizobium* inoculation at 6 locations in India. Means of 1981 and 1982 rainy-season data.

AICORPO locations	Not inoculated	Inoculated with NC 92	SE
Durgapura	1061	1354	±76
Jalgaon	1428	1761	±72
Kadiri	1322	1249	±75
Ludhiana	1370	1481	
Tirupati	1875	1785	±118
Junagadh	1083	1522	±60

Source: AICORPO Groundnut Annual Progress Report, v. II, Apr 1983. Directorate of Oilseeds Research, Rajendranagar, Hyderabad.

ful groundnut selections with high yield and disease resistance (Table 46).

Regional Program for Southern Africa

The ICRISAT Regional Groundnut Improvement Program for Southern Africa at Chitedze Agricultural Research Station, Lilongwe, Malawi was established in September 1982 with one plant breeder. Cooperating with national research and development programs, ICRISAT's program aims to develop high-yielding breeding lines and populations adapted to the region's different agroecology zones with resistance to factors that limit small farmers' production. Breeding for resistance to the major diseases in the region receives top priority.

The Chitedze Agricultural Research Station is 16 km west of Lilongwe at 14°S and 33.45°E with an altitude of 1050 m. The Lilongwe Plain where Chitedze is situated has a tropical continental climate with one rainy season from November to April: mean annual rainfall ranges from 750 mm to 875 mm and mean annual atmospheric temperature, 18 to 21°C.

Weather at Chitedze

Data on rainfall, temperature, and sunshine hours per day are presented in Table 47. A total of 678 mm of rain was recorded during the rainy season (November 1982 to April 1983). The season characteristically included dry periods from

Table 46. Some useful groundnut selections made by cooperators from the segregating material supplied by ICRISAT.

Line[1]	Scientist/Location	Remarks
CGC 4007	Project Coordinator	Rust and drought resistant, being tested in AICORPO/FDRVT
CGC 4018	Project Coordinator	Rust and drought resistant, being tested in AICORPO/CVT
VG 5	Breeder, Vridhachalam Tamil Nadu	High-yielding lines, being tested in state adaptive trials
VG 18		
VG 19		
TI 2	Breeder, NARP[2] Tirupati, A.P.	High-yielding lines, being tested in state trials
TI 18		
TI 21		
RGr 143	Breeder, Durgapura Rajasthan	High-yielding lines
RGr 155		
RGr 158		
RGr 176		
NFG 5	National Fellow IARI Regional Stn. Rajendranagar, Hyderabad	High-yielding lines; being tested in AICORPO/IET

1. Designated by the scientist who made the selection. 2. NARP = National Agricultural Research Project.

1 to 9 and 16 to 24 November; 18 to 28 February; and 9 to 15 and 20 to 30 April.

Table 47. Rainfall, temperature, and sunshine hours at Chitedze, Malawi, crop season 1982/83.

Months	Rainfall (mm)	Temp (°C) Max.	Min.	Sunshine hrs/day
1982				
September	Trace	27.8	10.9	9.2
October	38.4	28.9	14.2	8.3
November	82.0	29.6	16.0	6.8
December	156.1	28.3	16.8	6.8
1983				
January	145.3	28.4	17.4	6.9
February	185.4	28.2	16.3	6.5
March	67.2	28.6	16.0	7.1
April	42.5	28.3	14.9	8.0
May	2.5	27.9	12.4	8.3
June	6.3	25.8	9.6	8.1
July	11.8	24.4	10.1	6.8
August	0	25.3	10.1	8.3
September	0	-	-	-
October	5.3	30.3	14.6	9.1
November	14.2	32.4	17.4	9.5
December	185.0	28.3	18.1	4.7

Research Program

To start our program at Chitedze, we imported about 2000 germplasm lines and breeding populations (from F_2 to F_{10} generations) selected from projects for high yield and quality, earliness and foliar-disease resistance and from eight replicated yield trials at ICRISAT Center. We carefully selected lines and populations with attention on their origins, pedigrees, and performance at various locations in India.

ICRISAT Center sent a pathologist to assist the groundnut breeder during the January to April 1983 crop season.

Growing conditions. Our 5 ha area, with Ferric Luvisol soil, was fertilized with single superphosphate at 40 kg P_2O_5/ha. Planting started in late November, under dry conditions, on 60 cm ridges, and continued until 10 December 1982. A 55.4 mm shower fell 11 December 1982. All the material was grown under rainfed conditions with no plant protection measures.

Germplasm. Four hundred eighty-eight germplasm lines, mostly of South American and African origin, and 111 elite parents of known good combining ability and resistance to diseases and insects were evaluated in 6 m, unreplicated, single-row plots. Nine important varieties of the region were included as controls.

All 599 of these lines were evaluated by recording such morphological characters as growth habit, branching pattern, stem pigmentation and hairiness, leaf color, various pod and seed characteristics, days to emergence, days to 75% flowering, days to maturity, shelling percentage, and yield. The lines have been assigned ICRISAT Groundnut Malawi Numbers (ICGM) and have been documented in the Germplasm Accession Register.

Forty-one promising lines with pod yield of at least 1.0 kg per plot, or seed yield of at least 0.60 kg per plot, were selected for further evaluation during 1983/84.

Performance of some of the promising germplasm lines and controls is presented in Table 48. Some of the valencia types (*Arachis hypogaea* subspecies *fastigiata* var. *fastigiata*), particularly those from South America, performed well. Except in Zimbabwe, where valencia types are being phased out, they have previously received little attention in southern Africa.

None of the lines tested showed resistance to early leaf spot (*Cercospora arachidicola*). Defoliation ranged from 80 to 100%, 10 days before harvest. In some cases, though defoliation was severe, the lesions on the remaining leaflets were small and sporulation was extremely poor (Table 49). Germplasm line ICGM 189 (ICG 5216) showed low sporulation and small lesions; it also is one of the promising lines selected independently for yield.

Some of the lines—NC 3033, ICG 6340 (PI 350680), ICG 4747 (PI 259747) and ICG 7882 (PI 270608)—earlier reported resistant to *C. arachidicola*, were not resistant at Chitedze.

Table 49. Reaction of groundnut genotypes to early leafspot (*C. arachidicola*), Chitedze, Malawi, crop season 1982/83.

	Components of resistance			
Genotypes	Defoliation (%)	Infection frequency (lesions/cm^2)	Lesion diameter (mm)	Sporulation[1]
Germplasm				
ICGM 189 (ICG 5216)	80	15.1	2.0	1.8
ICGM 291 (ICG 8528)	85	19.2	2.2	2.0
ICGM 292 (ICG 8529)	80	20.5	2.5	1.5
Breeding Populations				
F_4				
(NC Ac 17133 -RF × TMV 2) F_2-B_1-B_1	90	1.2	9.2	5.0
F_7				
(TG 3 × NC Ac 17090) F_2-B_2 B_1-B_2-B_1-B_1	55	2.3	9.0	5.0
Control				
Chalimbana	85	3.0	8.5	5.0

[1] Extent of sporulation on a 5 point scale, where 1 = no sporulation, 5 = extensive sporulation.

Hybridization. Workers were trained in hybridization techniques, primarily to generate segregating material for rosette resistance and high yield and quality. A total of 197 crosses were attempted in the field. The 11000 pollinations carried out resulted in 117 successful crosses and a total of 651 hybrid seeds. Seeds in crosses varied from 1 to 35. The low success rate (5%) is primarily attributable to insufficient expertise among the workers, and to damage caused by rosette disease, *Hilda patruelis*, (a sucking bug), and dry weather.

Breeding for Disease Resistance

Foliar fungal disease. Early leaf spot (*Cercospora arachidicola*) first appeared about two weeks after groundnuts emerged and rapidly

Table 48. Promising groundnut germplasm lines compared with control varieties, unreplicated trials, Chitedze, Malawi, crop season 1982/83.

ICGM	ICG	Identity	Origin	Days to 75% flowering	Growth habit[1]	Branching pattern[1]	Days to maturity	Pod yield (kg/plot)	Shelling (%)	100 seed weight (g)	Cultivar group[2]
336	2384	NC Ac 17139 PI 313949	Bolivia	30	D3	A	124	1.41	59	58.3	Nambyquarae
471	3077	Abuya	-	23	D3 to E	S	124	1.12	72	34.9	Spanish and Valencia
437	453	NC Ac 2931 PI 152111	Brazil	26	E	S	124	1.09	74	41.7	Spanish
48	409	NC Ac 2696 PI 152132	Brazil	25	D3 to E	S	124	1.16	68	35.0	Valencia
197	6012	NC Ac 16142 PI 262093	Bolivia	27	E to D3	S	124	1.25	63	36.3	Valencia
479	4118	91176	India	22	E	S	124	1.07	73	35.8	Spanish to Manyema
177	5094	Nc Ac 16129 PI 262079	Brazil	25	D3	S	124	1.13	69	35.2	Valencia
189	5216	EC 24396 PI 262087	Brazil	23	E to D3	S	124	1.03	71	34.4	Valencia
449	1123	Natal Common	South Africa	22	D3	S	124	1.03	70	38.0	Valencia
456	1689	NC Ac 2884 PI 153169	Argentina	27	E	S	124	0.99	73	35.0	Spanish
		HG 1	India	26	E	S	130	1.21	59	30.6	Valencia
Control		Chalimbana	Ex. Malawi	30	D2	A	139	0.62	61	75.9	Virginia
		Mani Pintar	Ex. Malawi	30	E to D3	A	139	0.90	72	50.9	Nambyquarae
		Egret	Zimbabwe	29	E	A	139	1.09	52	48.2	Virginia
		Spancross	USA	26	E	S	124	0.70	69	29.4	Spanish
		RG 1	Malawi	29	D3 to E	A	139	1.01	62	50.1	Virginia
		E 879/6/4	Malawi	30	D2	A	139	0.85	61	77.7	Virginia
		SAC 58	Ex. Malawi	29	E to D3	A	139	1.08	52	53.7	Nambyquarae

1. As per Groundnut Descriptors, IBPGR, Rome, 1981. E = Erect, A = Alternate, D2 = Decumbent 2, D3 = Decumbent 3, S = Sequential.
2. As per Gibbons *et al.* (1972), Euphytica, 21:78-85.

became epidemic. This presented an opportunity to screen our breeding populations against the pathogen under high natural pressure, without artificial inoculation or specific planting arrangements. Reactions to *C. arachidicola* were recorded some 20 days before harvest. Defoliation percentages were estimated on central stems of five random plants per plot, using schematic diagrams depicting known percentages of leaflets lost.

Breeding populations. We planted a total of 338 populations (from F_1 to F_9 generations) in 1983. Days to 75% flowering ranged from 25 to 31 and to maturity, 125 to 138.

Early leaf spot caused extensive defoliation (75-100%) of all populations except one. Only two populations, one with somewhat less defoliation and another with low infection frequency merited further attention.

The breeding population (TG 3 × NC Ac 17090), though less defoliated, had larger lesions and extensive sporulation. On the other hand, germplasm line ICGM 292 had smaller lesions with sparse sporulation, even though defoliation and infection frequency were high. These genotypes could be used in the breeding program by combining their various resistance components.

As all populations were susceptible to early leaf spot, selections were made visually for high

Table 50. Performance of the 10 highest-yielding entries and other control varieties in groundnut rust yield trial, Chitedze, Malawi, crop season, 1982/83.

	Days to 75% flowering	Branching pattern[1]	Days to maturity	Yield (kg/ha)	Shelling (%)	100-seed wt.(g)
Mani Pintar (control)	28	A	132	2940	72	51.3
Egret (control)	30	A	132	2760	70	49.5
SAC 58 (control)	30	A	132	2600	65	53.6
(NC-Fla-14 × PI 259747) F_2-PP-B_1-B_2-B_2-B_3-B_1-B_1	29	S	118	2600	75	26.7
J 11 (control)	29	S	118	2530	68	31.4
(TG 3 × EC 76447 (292)) F_2-B_1-B_1-B_1-B_1-B_1-B_1	26	S	118	2470	71	35.9
(Ah 8254 × PI 259747) F_2-P_4-P_1-B_1-B_2-B_1-B_1-B_1	27	S	118	2450	76	27.7
(NC Ac 2190 × NC Ac 17090) F_2-B_1-B_2-B_2-B_2-B_1	26	S	118	2410	68	40.7
RG 1 (control)	30	A	132	2340	72	49.9
(Florigiant × NC Ac 17090) F_2-B_1-B_1-P_1-B_1-B_1	27	S	118	2320	62	31.2
Spancross (control)	28	S	118	2250	75	30.0
E 879/6/4 (control)	30	A	134	2030	70	81.3
Robut 33-1 (control)	30	A	118	2010	71	39.8
NC Ac 17090 (resistant parent)	26	A	118	1900	68	37.0
Chalimbana (control)	31	A	137	1570	68	8[illegible].3
SE				±131		
CV (%)				13.0		

1. A = Alternate branching (*A. hypogaea* subspecies *hypogaea* var. *hypogaea*)
S = Sequential branching (*A. hypogaea* subspecies *fastigiata*).

yield and superior pod characteristics. Of 161 bulk selections, only 6 were rated as good and 27 more as average to good. Pedigrees of two selections with good performance, (EC 76446 (292) × 87/4/7 (2)) F_2-B_1-B_1 and (HG 1 × NC Ac 17090) F_2-B_1-B_1-B_2-B_1-B_1-B_1 and two selections, (Colorado Manifredi × DHT 200) F_2-B_2(R) and (HG 1 × EC 76446 (292)) F_2-B_1-B_1-B_2-B_1-B_1, with average to good performance, were included in the Chitedze yield trial.

Yield trial. The trial consisted of 20 advanced rust-resistant breeding lines, 9 standard varieties including 2 from India, and a rust-resistant parent. Mani Pinta yielded the most followed by Egret and SAC 58 and rust-resistant (NC-Fla-14 × PI 259747) F_2-PP-B_1-B_2-B_2-B_3-B_1-B_1. Performances of the 10 highest yielding entries with yields of other control varieties are presented in Table 50.

The breeding lines and control variety Spancross (Table 50) belong to the same subspecies (*fastigiata*) and have a similar maturity period. Although they yielded more than Spancross, the differences were not significant. At Chitedze, however, the advantage of these rust-resistant lines could not be exploited fully because of severe early leaf spot and because rust appeared extremely late in the season. Under heavy rust attack they will probably significantly outyield Spancross.

Four of the breeding lines included in the trial, (NC-Fla-14 × PI 259747) F_2-PP-B_1-B_2-B_3-B_1-B_1 (ICRISAT Groundnut Malawi Selection (ICGMS) 27), (Ah 8254 × PI 259747) F_2-P4-P1-B_1-(ICGM 29), (NC Ac 2190 × NC Ac 17090) F_2-B_1-B_2-B_1-B_2-B_2 (ICGMS 30), and (TG 3 × EC 76446 (292)) F_2-B_1-B_1-B_1-B_1-B_1 (ICGMS 28) were further purified and included in the Regional Yield Trial (spanish bunch) primarily for their agronomic acceptability and relatively better yield. Some of these lines are expected to perform better in such areas as southern Mozambique and southeast Tanzania, where rust and late leaf spot are predominant.

Virus diseases. We evaluated 300 advanced cytogenetics lines derived from interspecific crosses for resistance to rosette disease by planting late (24 January 1983). Disease build-up was severe and uniform. Most of the lines developed 100% infection; 48 plant selections, including bulks, were made from the plants that did not have typical rosette symptoms.

We also assessed the germplasm and breeding lines of the Malawi national program for rosette resistance. Resistance of 44 lines was confirmed under field conditions. They belong to the virginia group (*A. hypogaea* subspecies *hypogaea* var. *hypogaea*) and include West African germplasm lines such as RMP 49, RMP 40, 48-37, 48-36, and 48-21 as well as several breeding lines developed in the Malawi national program.

We have intiated hybridization with some of these resistant sources to generate breeding material for rosette resistance.

Breeding for High Yield, Quality, and Earliness

Although development of high-yielding, disease-resistant breeding lines is the main objective of the program, substantial efforts and resources are used to develop early-maturing, high-yielding breeding lines based on yield alone. These lines do not resist diseases so they are intended for areas where some of the diseases are absent or of low intensity. Since such lines are selected and evaluated under nonprotected conditions, they apparently yield well under disease pressure without any obvious disease-resistant characteristics. They also are useful in disease-resistance programs.

Breeding material. Six hundred and forty-five populations representing F_1 to F_{10} generations were grown in various plot sizes under nonprotected conditions. Days to 75% flowering ranged from 21 to 35 and days to maturity from 108 to 138. All populations were highly susceptible to *C. arachidicola*. Selections were made visually mainly on the basis of yield and other seed and pod characteristics; 219 populations were rejected for poor yield and undesirable pod and seed characteristics. In the remaining 426 populations, 443 selections, mostly bulks, were made;

58 good selections were identified in various generations. Three of the good selections, (Colorado Manfredi × L.No. 95-A) F_2-B_2-B_2 (Red) (ICGMS 31), (NC Ac 2821 × MH 2) LF_2-B_1-B_1-NIB_2-B_1-B_1-B_1 (ICGMS 32), and (RMP 91 × DH 3-20) F_2-B_1-B_1-B_1 (ICGMS 47) were included in the Regional Yield Trials and 102 other selections with average or good performance were included in various station yield trials. The remaining were replanted for further selection.

Table 51. Performance of selected groundnut entries in various yield trials, Chitedze, Malawi, crop season 1982/83.

Identity	Yield (kg/ha)	Shelling (%)	100-seed wt.(g)
(JH 89 × Chico) F_2-B_1-B_1-NIB_1 -B_2-B_1-B_1-B_1	2780	77	32.1
Malimba (C_1)[1]	2460	75	32.7
SE	±190	-	-
CV (%)	20	-	-
JL 24	2390	74	40.6
(Tifspan × Robut 33-1) F_2-E-B_1-B_1 -B_1-B_1-B_1-B_1	2350	72	38.3
Malimba (C_1)	2110	65	32.3
SE	±110	-	-
CV (%)	10	-	-
(Robut 33-1 × NC Ac 316) F_2-B_1-B_1-B_1-B_1 -B_2-B_1-B_1-B_1	3380	72	41.6
Mani Pintar (C_2)[2]	2850	72	51.0
SE	±270	-	-
CV (%)	30	-	-
(USA 20 × IMV 10) F_2-P_3-B_1-B_1-B_1 -B_1-B_1-B_1-B_1-B_1	3460	73	64.0
RG 1 (C_2)	2270	66	46.2
JL 24	2610	74	36.3
Spancross (C_1)	2350	71	29.3
SE	±120	-	-
CV (%)	10	-	-

1. C_1 = Control variety belonging to subspecies *fastigiata* var *vulgaris*.
2. C_2 = Control variety belonging to subspecies *hypogaea* var *hypogaea*.

Yield Trials

Seven yield trials with entries ranging from 19 to 64 were planted in appropriate experimental designs in plots of three or four 6-m rows.

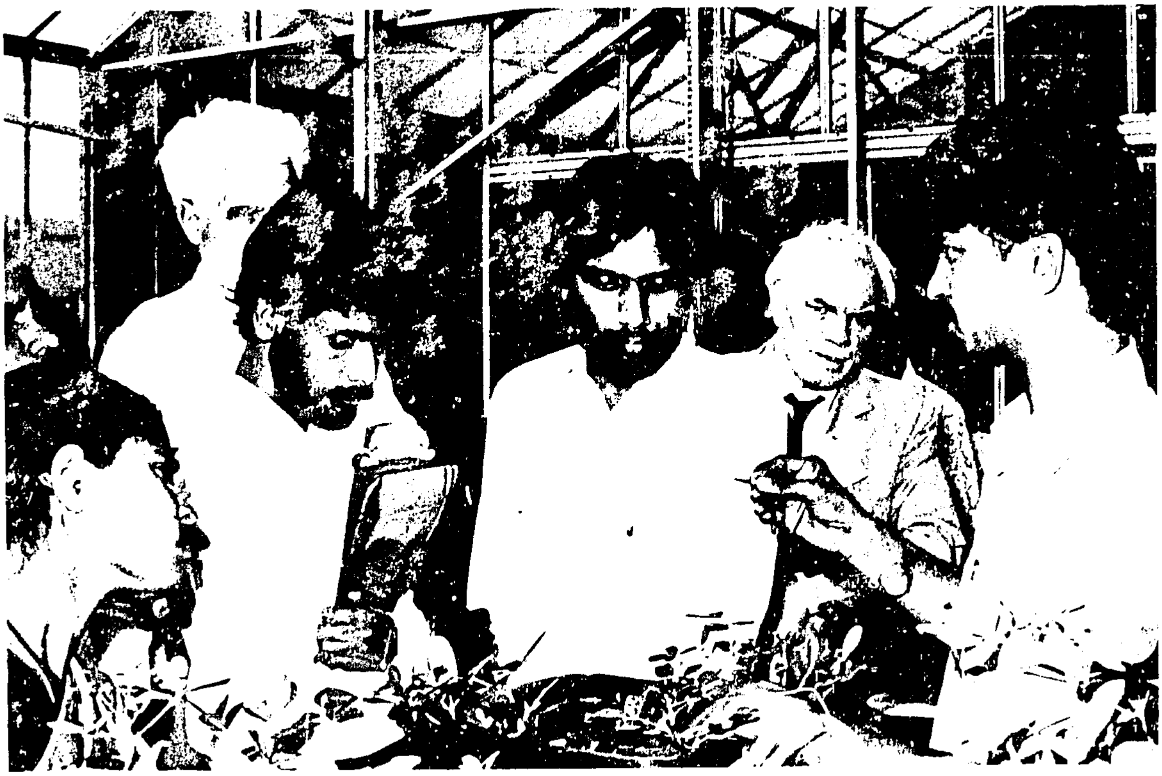
Mean yields of the trials varied from 1710 to 2277 kg/ha. The control, Mani Pintar, when included, generally performed the best, with few breeding lines exceeding its yield. The long growing period of Chalimbana, the predominant confectionery variety of Malawi, prevented it from doing well in any trial. Table 51 gives the performance of some of the test entries and the highest yielding control of the same botanical type.

Nearly half (46%) of the 226 test entries were rejected for poor yield; 54% were retained because they equalled or exceeded control varieties of the same botanical types or because they had poor emergence. Of these, 37 with better performance, after being assigned ICGMS numbers were included in the Regional Yield Trials for evaluation under various agroecological zones. The remaining entries were reorganized in station trials by botanical types.

Workshops, Conferences, and Seminars

Consultative Group Meeting for Asian Regional Research on Grain Legumes

Forty-eight participants representing research organizations in India, Indonesia, Japan, Malaysia, Nepal, Pakistan, Philippines, Thailand, ICRISAT and other international organizations with responsibilities for agricultural development in Asia met 11-15 December, at ICRISAT Center, to discuss ways that ICRISAT can help improve groundnut, chickpea, and pigeonpea production in the region, because production has fallen well below demand.



Cytogenetics Workshop participants get a close look at ICRISAT's work on groundnuts. Progress on use of *Arachis* wild species at various institutes was reviewed at the workshop.

The group agreed that a coordinated regional approach to research would be productive, and that an operational network of scientists and policymakers should be established. Particular attention should be paid to crop improvement and related cropping systems and socioeconomic research. Improvements are also needed in transfer of germplasm between research centers, training research staff, and exchange of information and advice, particularly among visiting specialists. The group's recommendations and executive summaries of the papers presented are available from Information Services, ICRISAT.

International Workshop on Cytogenetics of *Arachis*

Thirty participants attended the workshop, 31 October-2 November, to discuss current use of wild species, and to review progress at various institutes where active work with wild species is in progress. Reports were presented from many countries, ranging from Australia to Brazil. The participants discussed ways to extend the collection of the 70 known wild species, so that a wider range of characters can be made available to plant breeders. They also reviewed techniques such as hybridization, treatment with plant growth hormones, and tissue culture, by which desirable genes can be transferred to cultivated groundnut. Proceedings will be available from Information Services, ICRISAT.

Group Discussion on Management of Pests and Diseases of Groundnut with Special Reference to Resistance Breeding

Forty-eight scientists from India and 17 from ICRISAT participated in group discussions held

26-29 September at ICRISAT Center. In addition to papers on germplasm, breeding, cytogenetics, pathology, entomology, and physiology, topics covered in the discussions included foliar diseases, mycotoxins and pod rots, nematode diseases, virus diseases, and insect pests. Proceedings will be available at a future date from Groundnut Improvement Program, ICRISAT.

Looking Ahead

Diseases. Screening germplasm lines, breeding lines, and derivatives of hybrids between groundnut and wild *Arachis* spp for resistance to major groundnut diseases will continue. Identified resistant genotypes will be used in breeding programs with greater emphasis on important diseases in significant SAT areas outside India, such as rosette virus disease in Africa, bacterial wilt (*Pseudomonas solaracearum*) in East and South-East Asia, and mycoplasma-induced witches broom in East Asia.

Research on early leaf spot will be increased both at ICRISAT Center and at the ICRISAT Regional Program for Southern Africa. In cooperation with the Farming Systems Research and Economics Programs research will be expanded on local farms to assess the economic value of rust and late leaf spot resistant lines and develop management practices for them.

Research on pod rots and on the aflatoxin problem will continue to receive high priority. Resistance to preharvest seed invasion needs more emphasis, as does aflatoxin contamination, especially under rainfed and drought situations.

Insect pests. Efforts will continue to find sources of resistance to major groundnut pests and to use sources found in breeding programs. Developing of multiple pest resistance will remain the major objective. Greater emphasis will be given to pest problems important in Africa and East Asia. We hope to investigate vector systems of rosette and witches broom diseases.

Research should commence on groundnut storage problems with the aim of using genetic resistance to the most important storage pests.

Drought, nutrient stress, and photoperiod. We hope to increase drought screening to process 2500 lines each year. Basic research on nutrient stress, photoperiod responses, and their interactions with diseases and other environmental factors will continue until information is adequate to optimize screening processes.

Research on adaptation to temperature will be initiated.

Research will continue on *Rhizobium* inoculation, inoculum quality, and factors influencing efficiency of biological nitrogen fixation. Studies will be initiated on the role of mycorrhiza in groundnut nutrition.

Plant improvement. Breeding for resistance to stress factors will continue as will adaptive breeding for particular traits and to fit cultivars to specific environments. As we identify sources of resistance to pests, diseases, and seed dormancy and sources to improve yield, quality, and earliness we will incorporate them into the various breeding programs.

High priority will be given to organizing regional germplasm evaluation trials in Africa and Asia. The ICRISAT Regional Program for Southern Africa will facilitate this work. A similar program should start soon in West Africa.

Wild species. Wild species must be screened for resistance to a wider range of diseases, with emphasis on diseases that *A. hypogaea* does not resist. Several important diseases do not occur in India so our wild species collection should be established at other research centers to facilitate their screening.

Research in cytogenetics must increase, orientated specifically to help breeders with improvement of *A. hypogaea.* Attention must be paid to producing haploids, to systems that control chromosome pairing and recombination, and to developing aneuploids to facilitate gene transfer and genetic analyses. Similarly, tissue and cell culture must play a wider role in crop improvement with full exploitation of induced and spontaneous somoclonal variation.

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FARMING SYSTEMS

Contents

Resource Evaluation 233
Delineation of Benchmark Vertisols in India 233
Insect Surveys 233

On-Station Component Research 235
Microclimatological Studies 235
Water Use and Water-Use Efficiency of Cropping Systems 235
Response of Groundnut to Drought Stress 236
Crop-Weather Modeling 239
Sorghum 239
Pearl Millet 242
Resource Conservation 243
Baseline Data for Conservation Planning 244
Management Alternatives for Conservation Planning 246
Traditional Runoff-Storage Tanks 249
Intercropping Studies 251
Millet vs Sorghum as an Intercrop with Pigeonpea 251
Three-Component Intercrop: Millet/Groundnut/Pigeonpea 253
Nutrients 255
Nitrogen Fertilization Strategies 255
Efficiency of Fertilizer Nitrogen 257
Fertilizer Placement 259
Phosphorus 259
Maintenance of Soil Fertility 260
Organic Matter Decomposition 265

On-Station Operational Research 265
Cropping Systems for Different Soil Types 265
Deep Black Soils 265
Medium Black Soils 267
Shallow Black Soils 267
Alfisols 267
Fertilizer and Seed-Planter Unit 268
Mechanical Weed Management 272

Evaluation at National Research Centers 272
Begumganj 274
Talod 275

On-Farm Verification Trials 275
On-farm Testing of Improved Vertisol Management Technology 275
Economic Aspects 279
Lessons learned from On-Farm Verification Trials 281
Cropping Entomology Studies 281
Support to Manufacturers of Improved Equipment 284

International Cooperation 286
Resource Evaluation 286
Agroclimatology: 286
Toposequence studies: Upper Volta 289
Component Research 292
Millet Agronomy: Niger 292
Sorghum Agronomy: Nigeria 295
Soil Fertility: Niger 298
Soil and Water Management: Upper Volta 298

Workshops Conferences, and Seminars 301

Looking Ahead 303

Publications 305

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232

FARMING SYSTEMS

This year, the Farming Systems Research Program took two important steps. First, it launched a subprogram to intensify research aimed at optimizing land productivity through reduced erosion and effective conservation of soil and water resources. The priority objectives of this research are to quantify the rainfall erosion potential of major SAT soils; determine, quantitatively, the effectiveness of alternative land uses; and integrate the findings with information for developing improved farming systems technolgies applicable to small farms of the SAT. The first season's results are included in this report.

The second step was to identify priority areas for research and establish working groups of interdisciplinary research teams from ICRISAT, International Livestock Center for Africa (ILCA), International Fertilizer Development Center, USA (IFDC), and Texas A&M University-based scientists at ICRISAT Sahelian center, Niger. The following areas for research were outlined: soil and water conservation, soil and fertilizer management, nutrients, cropping systems, economics, social anthropology and land tenure, farm livestock management, agroforestry, and evaluation of Farming Systems Research for the West African SAT.

In 1984, we will devote special attention to integration of crops and animal production systems, the role of agroforestry systems in arable lands, on-farm research, and verification of technologies generated at ICRISAT in farmers' fields, in cooperation with national research and development institutions.

Resource Evaluation

Delineation of Benchmark Vertisols in India

In April 1982 a cooperative project was initiated by the ICAR's National Bureau of Soil Survey and Land Use Planning and ICRISAT on a Benchmark Soils Network for Agrotechnology Transfer, with the following objectives:

1. to predict the suitabilities of some available new technologies for use on Vertisols and associated soils in central India;
2. to determine the value of a benchmark soils network for planning agricultural research and land use in India;
3. to examine critically the present criteria for establishing taxa for Vertisols in soil taxanomy.

The data for morphological characteristics, physical and chemical properties, and climatic and geomorphologic situations for 15 soil series representing 12 soil families in central peninsular India have been compiled. A 1:1 million scale soil map representing the areal extent of the soils in the region has been prepared in great-group associations. Detailed soil maps, along with soil survey interpretive groupings, were completed for the sites of On-farm Verification Trials at Begumganj, Kanzara, Taddenpally, and Sultanpur. Crop performance and land use data by 100 practicing farmers in villages have been compiled for 5 soil series, and work is in progress to collect similar data from other soils. Analyses of these data will help explain the inherent constraints affecting crop performance in Vertisols soil families and assist objective selection of on-farm sites to verify emerging ICRISAT technologies.

Insect Surveys

Insect attacks on our cropping systems, especially those including improved cultivars, can cause serious loss of potential yield. We are, therefore, studying major pests and their predators, using several approaches.

Table 1. Counts[1] of some important insect pests caught in a light trap on a Vertisol watershed, ICRISAT Center, 1978-83.

	1978-79	1979-80	1980-81	1981-82	1982-83
Legume borers					
Adisura marginalis	990	343	268	2835	813
Adisura stigmatica	4212	1713	1586	7196	1511
Etiella zinckenella	6650	5385	7549	13002	3982
Heliothis armigera	10633	18019	7653	37524	15944
Maruca testulalis	1877	995	1092	1000	2470
Cereal pests					
Chilo partellus	4088	17882	18635	4154	9490
Mythimna separata	2097	208	280	186	323
Groundnut pest					
Spodoptera litura	4406	3401	10491	7708	3601

[1] Insects counted June to May for each indicated year.

Traps. We continuously record catches of a wide range of insects, both pests and their natural enemies, in 3 light traps at ICRISAT Center. This trapping record provides valuable information on the seasonal incidence of major insect pests of our mandate crops (Table 1). The trap catches confirm our observations that legume pest populations were within the normal range in 1983, including that of *Heliothis armigera*, which was particularly high in the previous year.

A few other locations in India are used to provide data from light traps. However, the pheromone trap, which is convenient to operate, is being used regularly at many centers in India and abroad by the Pulse Entomology Subprogram. We collaborate with the operators of these traps, and with the insect ecologists of the Tropical Development and Research Institute, London, to determine the incidence and movement of a few insect pests, such as *Heliothis* and *Spodoptera*.

Intercrops at ICRISAT Center. This year, we included sorghum/pigeonpea, millet/pigeon-

Table 2. *Heliothis* infestation, insect pod damage, and yield of intercropped pigeonpea on Alfisols, ICRISAT Center, 1982-83.

Cropping system	*H. armigera* peak infestation (no/plant)		Pods damaged (%) by				Insect damage (%)	Pod yield (kg/ha)
	Eggs	Larvae	Borer	Podfly	Hymenoptera	Bruchid		
Sorghum/ pigeonpea	4.2	2.7	48.4	10.7	1.7	2.6	60	680
Pearl millet/ pigeonpea	4.9	2.6	84.4	4.5	2.2	1.6	89	330
Groundnut/ pigeonpea	4.2	2.9	71.5	10.7	3.9	1.2	81	390
SE	±1.67	±0.10	±4.88	±0.38	±1.68	±0.28	±4.0	±188

pea, and groundnut/pigeonpea on Alfisols in our monitoring of *H. armigera* infestations in intercrops at ICRISAT Center. *H. armigera* infestations on pigeonpea in these three systems were similar, although insect damage appeared to be somewhat higher in the groundnut or millet intercrop than with sorghum (Table 2). This observation needs to be confirmed by a large-scale trial.

Surveys. We continued our survey of the parasitoids of *H. armigera* on chickpea in Andhra Pradesh, Maharashtra, and Karnataka. Of more than 4000 larvae collected during November-December, 28.5% were parasitized by the hymenopteran *Campoletis chlorideae*, and 0.7% by the dipteran *Carcelia illota*. The other parasite detected in the collection was *Sturmiopsis inferens*, but it was only found in small numbers.

We have so far collected more than 200000 larvae of *H. armigera* and recorded 29 different parasites. *Campoletis chlorideae* is found in most of the hosts, throughout the year, although its incidence varies with host and month.

On-Station Component Research

Microclimatological Studies

Water Use and Water-Use Efficiency of Cropping Systems

We studied water use and water-use efficiency (WUE) of selected cropping systems on an operational scale on a deep Vertisol, medium-deep Vertisol, Vertic Inceptisol, and Alfisol in cooperation with our Cropping Systems Subprogram scientists. We installed neutron-probe access tubes and monitored changes in soil water content, weekly from the beginning of the rainy season through the postrainy season. Probe observations were taken at 15-cm intervals from 30-cm soil depth to 187 cm in Vertisol, 157 cm in medium-deep Vertisol, 157 cm in Vertic Inceptisol, and 127 cm in Alfisol. Moisture in the 0-10 cm and 10-22 cm depths was determined gravimetrically. Water use (evapotranspiration) was calculated by the water balance method, i.e.,

$$P+I = ET+R+D+\Delta M$$

where

P = precipitation,
I = irrigation,
ET = evapotranspiration,
R = runoff,
D = drainage, and
ΔM = change in soil water content.

No irrigation was used. Rainfall was uniformly distributed during the 1982-83 cropping season with only 1 or 2 runoff events. Runoff was not measured. Average runoff from adjoining plots was used to calculate effective rainfall. Deep drainage was assumed to be zero. Water-use efficiencies for seed yield produced by the cropping systems were calculated as follows:

$$\text{WUE for seed yield} = \frac{\text{total seed yield}}{\text{seasonal water use}}$$

On the deep Vertisol significantly more water was used by sorghum/pigeonpea (intercrop) and sorghum-safflower (sequential crop) than cowpea/pigeonpea, maize-chickpea, and sorghum-chickpea cropping systems at low fertility (Table 3). Cropping systems other than sorghum/pigeonpea and sorghum-safflower did not differ in water use. At medium fertility, maize/pigeonpea used significantly more water than mungbean-sorghum and sorghum-chickpea. Sorghum-chickpea used least water at both fertility levels. WUE for seed yield was highest for sorghum-chickpea at both fertility levels followed by maize-chickpea, sorghum-safflower and sorghum/pigeonpea. The lowest WUE for seed yield was by cowpea/pigeonpea and mungbean/sorghum, at both fertility levels. Water use by cropping systems did not increase with increase in fertility, but WUE for seed yield increased.

On the medium-deep Vertisol sorghum-safflower used significantly more water than other cropping systems at low fertility; but at medium fertility it differed significantly only from sorghum-chickpea (Table 3). The legume-based cropping systems, except those involving

Table 3. Water use and water-use efficiency (WUE) of cropping systems at low (F_0) and medium (F_1) fertility on deep and medium-deep vertisols, 1982-83 season, ICRISAT Center.

	Water use (cm)		WUE for seed yield (kg/ha per cm)	
Cropping systems	F_0	F_1	F_0	F_1
Deep Vertisol				
Sorghum/pigeonpea	73.7	65.9	32	58
Maize/pigeonpea	70.0	70.2	30	48
Cowpea/pigeonpea	68.3	67.4	20	22
Sorghum-chickpea	67.2	64.5	45	68
Maize-chickpea	67.8	66.7	39	61
Sorghum-safflower	73.4	67.0	38	58
Mungbean-sorghum	71.5	64.9	29	43
SED 1[1]	±2.5	±3.0		
SED 2[2]	±4.3	±9.0		
Medium-deep Vertisol				
Sorghum/pigeonpea	66.3	65.3	48	70
Sorghum-chickpea	63.2	62.4	49	88
Sorghum-safflower	70.6	67.5	35	77
Mungbean-sorghum	60.6	63.6	18	36
SED 1	±2.0	±5.0		
SED 2	±2.8	±5.0		
Vertic Inceptisol				
Sorghum/pigeonpea	63.8	60.5	35	71
Millet/pigeonpea	61.4	60.2	36	53
Groundnut/pigeonpea	60.8	61.9	36	32
Mungbean/castor	59.3	60.2	19	28
SED 1	±1.2	±6.0		
SED 2	±1.6	±5.0		
Alfisol				
Sorghum/pigeonpea	59.7	57.7	22	38
Millet/pigeonpea	58.0	58.3	24	30
Groundnut/pigeonpea	57.9	57.3	15	18
Mungbean/castor	56.3	57.5	15	24
Millet/groundnut	56.0	55.0	12	16
SED 1	±1.9	±4.0		
SED 2	±1.8	±3.0		

1. SED =SE of difference between cropping system means at the same level of fertility.
2. SED =SE of difference between fertility means for the same cropping systems.

pigeonpea, used less water than the cereal-based cropping systems. Maximum WUE for seed yield was by sorghum-chickpea at both fertility levels, followed by sorghum-safflower and sorghum/pigeonpea. Lowest WUE for seed yield was by mungbean-sorghum at both fertility levels. Increase in fertility did not increase the water use by cropping systems, but WUE for seed yield was greater in medium fertility than low fertility.

These results on water use and WUE indicate that, for efficient use of resources on both deep and medium-deep Vertisols, the best cropping systems are sorghum/pigeonpea, sorghum-chickpea, and sorghum-safflower at both soil fertility levels. The maize-chickpea sequential system is also efficient on deep Vertisols.

On the Vertic Inceptisol maximum water use at low fertility was by sorghum/pigeonpea. The other cropping systems did not differ significantly (Table 3). At medium fertility none of the cropping systems differed significantly in water use. Millet/pigeonpea, groundnut/pigeonpea, and sorghum/pigeonpea did not differ in WUE at low fertility. At medium fertility sorghum/pigeonpea had maximum WUE followed by millet/pigeonpea, and groundnut/pigeonpea. Mungbean/castor had the lowest WUE at both fertility levels.

On the Alfisol, the cropping systems did not differ statistically in water use at either fertility level. WUE for seed yield was greatest in sorghum/pigeonpea and millet/pigeonpea, and least in millet/groundnut at both fertility levels.

The results on water use and WUE indicate that, on Vertic Inceptisols and Alfisols, the sorghum/pigeonpea and millet/pigeonpea cropping systems were the most efficient, at both fertility levels. Groundnut/pigeonpea also had a good WUE at low fertility. Millet/groundnut and mungbean/castor were relatively poor in WUE for seed yield.

Response of Groundnut to Drought Stress

Last year we reported results on the response of groundnut to water deficiency at various plant growth stages. Early droughting in groundnut (from emergence to peg initiation) increased groundnut yields, whereas moisture deficiency at other times decreased the yield. This year we put more emphasis on response to early stress. We also studied emergence, seedling vigor, and yield of groundnut grown from seeds of a groundnut crop stressed at various plant-growth stages in the previous season.

Groundnut productivity from seeds with moisture deficit history. Seed samples of groundnut (cv Robut 33-1) were collected from various stress treatments of a 1981-82 postrainy season experiment to determine the effect of seeds with moisture deficit history on seedling vigor and crop yield. Designs of experiments that produced the seeds used were:

T_1. Line source irrigation at 5 and 15 days after crop emergence (DAE), followed by 30 days stress to initiation of pegs, then no stress.

T_2. No stress to first flush of flowering (35 DAE); line source irrigation, then stress from flowering to last pod set; then no stress

T_3. No stress to first kernel (87 DAE); line source irrigation, then stress from pod filling to maturity.

T_4. Continuous stress.

For each of the 4 treatments, we measured the amount of water received in regions A, B, and C, which were 3, 9, and 15 m away from the line source (see ICRISAT Annual Report 1982 pp. 236-241).

Groundnut seeds collected from the above experiment were sown 19 June 1982 and emerged 24 June. The experiment was conducted in a randomized block design with 3 replications.

The seeds with previous moisture deficit history from emergence to initiation of pegging (T_1) recorded the highest mean final plant density, pod yield, and shelling percentage (Table 4). Mean seedling emergence percentages were 74, 62, 68 and 66, respectively, for treatments 1 to 4. In T_1, emergence percentage was highest in region C (78%) and lowest in region A (70%).

Table 4. Final plant population, pod yield, and shelling (%) of groundnut crop obtained from seeds with previous history of moisture deficits, rainy season, 1982.

Treatment	Seedling emergence (%)	Final plant population/ (10^3 pl/ha)	Pod yield (kg/ha)	Shelling (%)
1A	70	148	1890	71
1B	74	138	1820	61
1C	78	156	1880	63
2A	67	126	1850	55
2B	69	148	1510	60
2C	51	110	1250	69
3A	67	147	1820	55
3B	68	126	1780	57
3C	68	122	1620	60
4A	70	151	1750	66
4B	63	129	1760	57
4C	64	127	1640	61
SE	±6	±8	±92	±5

Effect of early moisture deficits (EMD) on groundnut productivity. To study the effect of early moisture deficits (EMD) on groundnut productivity, two cultivars of groundnut (TMV 2 and Robut 33-1) were sown 19 June 1982. The experiment was conducted in split-plot design with moisture treatments in the main plot and cultivars in the sub-plot, with two replications. The crop emerged 24 June. EMD was induced by covering the experimental plots with a black polyethylene sheet. The sheet was removed at peg initiation (44 DAE), by which time it had prevented 233 mm of the total of rainfall received during the rainy season (656 mm) from entering the covered plots. Measurements were made on in both the covered and uncovered plots of dry-matter production (partitioned to various plant parts), crop yield, water use, and water-use efficiency.

Apparent increases in final plant populations and yields of components (pods, kernels, and haulms) in the EMD treated plots were not significant (Table 5). However, EMD significantly reduced evapotranspiration (ET) throughout the life of both groundnut cultivars (Table 6); the

Table 5. Final plant population, pod and kernel yields, and yield components of two groundnut cvs TMV 2 and Robut 33-1 under the two moisture treatments[1], ICRISAT Center, rainy season 1982.

	Cultivar			
	TMV 2	Robut 33-1	SED[2]	SED[3]
Final plant population/ha ('000)				
EMD[1]	143	134	±17.5	±17.2
N[1]	124	125		
Pod yield (kg/ha)				
EMD	1450	1610	±216	±199
N	1200	1260		
Kernel yield (kg/ha)				
EMD	850	890	±145	±125
N	680	810		

1. EMD = Early moisture deficit (covered treatment); N = Natural moisture regime (not covered).
2. SED = SE of differences between cultivar means at the same moisture treatment.
3. SED = SE of differences between moisture treatment means for the same or different cultivars.

reduction was particularly large over the 25-50 DAE period, but was still appreciable (about 22.5%) over the 51-116 DAE period. EMD reduced the total ET over the crop growth period in TMV 2 and Robut 33-1 by 145 mm and 135 mm less, respectively. Water-use efficiency and harvest index of both cultivars was greater after EMD.

Effect of moisture deficiency at different phenological stages of groundnut. To study groundnut productivity of plants stressed at different phenological stages, we used the line source, sprinkler-irrigation technique to create a range of stress treatments. The experiment was sown 29 October 1982 in a split-plot design with four replications. Emergence was complete by 5 November. Main plot treatments were:

T_1. Line source at emergence; stress imposed from emergence to flowering (1 to 29 DAE); no stress after that.

T_2. Line source at emergence; stress imposed from emergence to pegging (1 to 47 DAE) by line-source irrigation; no stress after that.

T_3. Line source at emergence; stress from flowering to last pod set (29 to 92 DAE) by line-source irrigation.

T_4. Continuous stress imposed by line-source irrigation every 7 days.

In each main plot treatment, the groundnut rows ran parallel to the line source and plot width extended up to 18 m on either side of the sprinkler line. Considering the amount of water applied as a function of distance from the line source, we made measurements 3, 9, and 15 m from the line source; these were sub-plots. Net amount of water applied and evapotranspiration observed in various treatments are given in Table 7. We studied stomatal conductance, transpiration, water use, soil penetration resistance, yield, and yield components in various stress treatments.

Seasonal pattern in stomatal conductance in the treatments subjected to stress from emergence to flowering (T_1) and emergence to peg

Table 6. Evapotranspiration, water-use efficiency, and harvest index of two groundnut cvs TMV 2 and Robut 33-1, under two moisture treatments[1], ICRISAT Center, 1982.

Days after emergence (DAE)	Cultivar				
	TMV 2		Robut 33-1		
	EMD[1]	N[1]	EMD	N	SED
	Evapotranspiration (mm)				
25-50	29	126	32	121	±0.5
51-116	159	206	162	208	±1.5
Total	188	333	194	329	±1.2
	Water-use efficiency (kg/ha per cm)				
Total	45	20	46	25	±0.3
	Harvest index (%)				
Total	40	32	48	40	±0.4

1. EMD = early moisture deficit (covered treatment); N = natural (not covered).

Table 7. Amount of water applied and evapotranspiration (ET) in different treatments, ICRISAT Center, postrainy season 1982-83.

Treatment	Distance from the line source (m)	Net amount of water applied (mm)	ET (mm)
T_1	3	665	592
	9	657	603
	15	623	611
T_2	3	630	576
	9	589	546
	15	522	494
T_3	3	603	546
	9	553	515
	15	477	401
T_4	3	739	687
	9	409	386
	15	27	47

initiation (T_2) indicated considerable recovery in stomatal activity by the leaves after the stress was released (Fig. 1). The decrease in stomatal conductance in the treatments with stress imposed from flowering to last pod set was considerably greater than in the other treatments. The least stomatal conductance was seen in the plants subjected to continuous moisture deficit at 47 mm ET.

A dry surface soil during gynophore elongation and pod development hinders peg penetration and pod development in the soil. We measured soil resistance to penetration (SPR) during the pod development period (DAE 44 to 107). Highest value (64 kg/cm) of SPR was in T_3 at 401 mm ET (Fig. 2). Generally, SPR increased with decreasing ET.

Measurement of components of yield gave results in accord with those obtained previously. In groundnut, flowering to last pod set is the period when the plant is most sensitive to moisture deficiency; stress at this time results in lower yields due to reduction in both photosynthesis and pod development, as indicated by higher stomatal resistance and soil resistance to penetration.

Crop-Weather Modeling

Sorghum

Crop-weather models controlled by daily weather variables enable us to quantitatively describe the dynamics of crop-production systems. Such descriptions have potential for yield forecasting and crop management. The sorghum simulation model (SORGF) has therefore been revised to improve the accuracy of phenology prediction, light interception, soil water, total dry matter, and grain yield. The revised model was tested with independent data sets from multilocation, collaborative trials (ICRISAT Annual Report 1982 pp. 285-289).

Application of SORGF. We used the revised SORGF model to provide initial answers to questions regarding the screening of environments for sorghum production, selecting appropriate dates of sowing, and predicting when and how much irrigation water to apply for optimum grain yield. To test our predictions for optimum sowing dates for sorghum, we compared simulation results with observed data (Fig. 3) from the date-of-sowing experiments conducted by sorghum breeders during the 1979-80 postrainy season at ICRISAT Center. We predicted that delayed planting would lower grain yield; this was confirmed by the breeders' results. Early planting is the best in the postrainy season at ICRISAT Center. The highest yield (4527 kg/ha) resulted from a 12 September planting; planting on 29 November resulted in an 85% reduction.

The revised SORGF model also was used to estimate sorghum production potentials at Bamako and Tombouctou in Mali. Historical weather data (rainfall and temperature) were used and cumulative probability distributions were constructed for sorghum grain yields. Our analyses showed that under adequate management, rainfed sorghum can be grown reliably in Bamako; but, in Tombouctou it involves high risk without irrigation.

The simulated response of sorghum to assumed drought stress at different growth

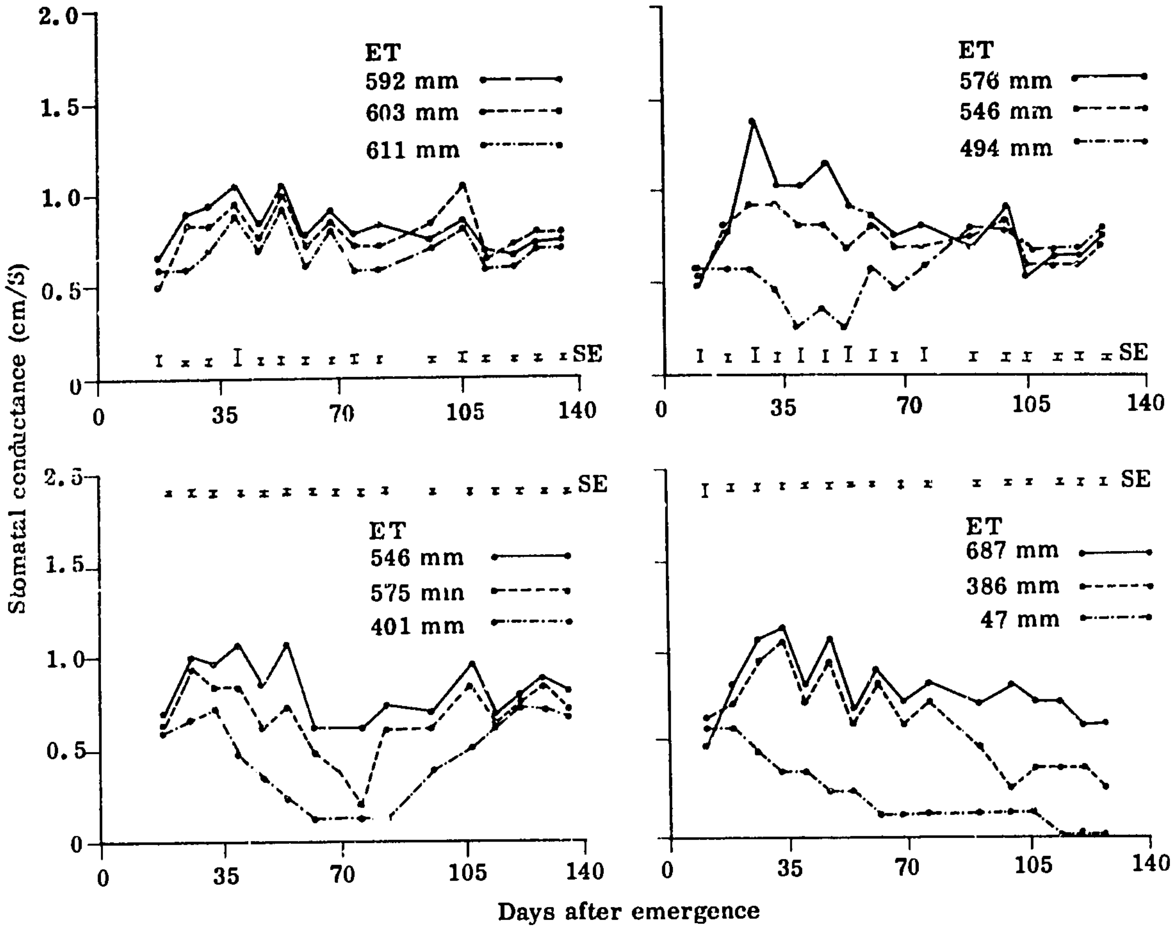


Figure 1. Seasonal variation in the stomatal conductance at different ET levels for different drought stress treatments, ICRISAT Center, postrainy season 1982-83.

stages also was assessed for Bijapur (Karnataka, India) where mean annual rainfall is 646 mm. The results showed that if drought stress could be relieved at crop establishment and anthesis, an average grain yield of 3200 kg/ha could be achieved with adequate management (Table 8).

A simple regression model. We analyzed 48 data sets from collaborative multilocation experiments to develop simple regression models to predict sorghum grain yield from one or more of these variables: soil water at planting, rainfall, mean temperature, solar radiation, and evapotranspiration for the crop growing season and for 3 growth stages. The growth stages were: emergence to panicle initiation (GS_1), panicle initiation to anthesis (GS_2), and anthesis to physiological maturity (GS_3). Stepwise regression techniques and Mallow's Cp criterion were used to select models. No single environmental factor could sufficiently explain the variability in grain yield. The following model, which had an R of 0.73 and the lowest Cp value, was selected; tested with 11 independent data sets, it explained 59% of the variation in grain yield:

$$Y = 782.11 + 7.8741\ (\pm 1.9345)SW - 0.2403(\pm 0.132)R_2T_2 - 0.1232\ (\pm 0.0354)\ R_2ET_2 + 0.0539\ (\pm 0.009)\ R_3ET_3 + 0.719(\pm 0.1322)\ R_2SR_2$$

where

Y = Observed grain yield (kg/ha)
SW = Available soil water (mm) at planting
R_2T_2 = Product of total rainfall (mm) and mean temperature (°C) in GS_2
R_2ET_2 = Product of total rainfall (mm) and evapotranspiration (mm) in GS_2
R_2ET_2 = Product of total rainfall (mm) and evapotranspiration (mm) in GS_3
R_2SR_2 = Product of total rainfall (mm) and solar radiation (ly/day) in GS_2

and

standard errors of regression coefficients are given in parentheses.

Table 8. Simulated sorghum grain yields under assumed stress levels at different growth stages during the postrainy season at Bijapur, Karnataka (simulation base: 16 years). Sowing date assumed to be 15 September.

Stress levels at			Grain yield (kg/ha)		
Sowing	Panicle initiation	Anthesis	Mean	Max	Min
×	×	×	2130	4260	1490
+	×	×	2180	4260	1490
+	×	+	2410	4260	1670
+	×	+	3210	4260	2350
+	+	+	3430	4260	2580

× No water applied.
+ 50 mm of water applied.

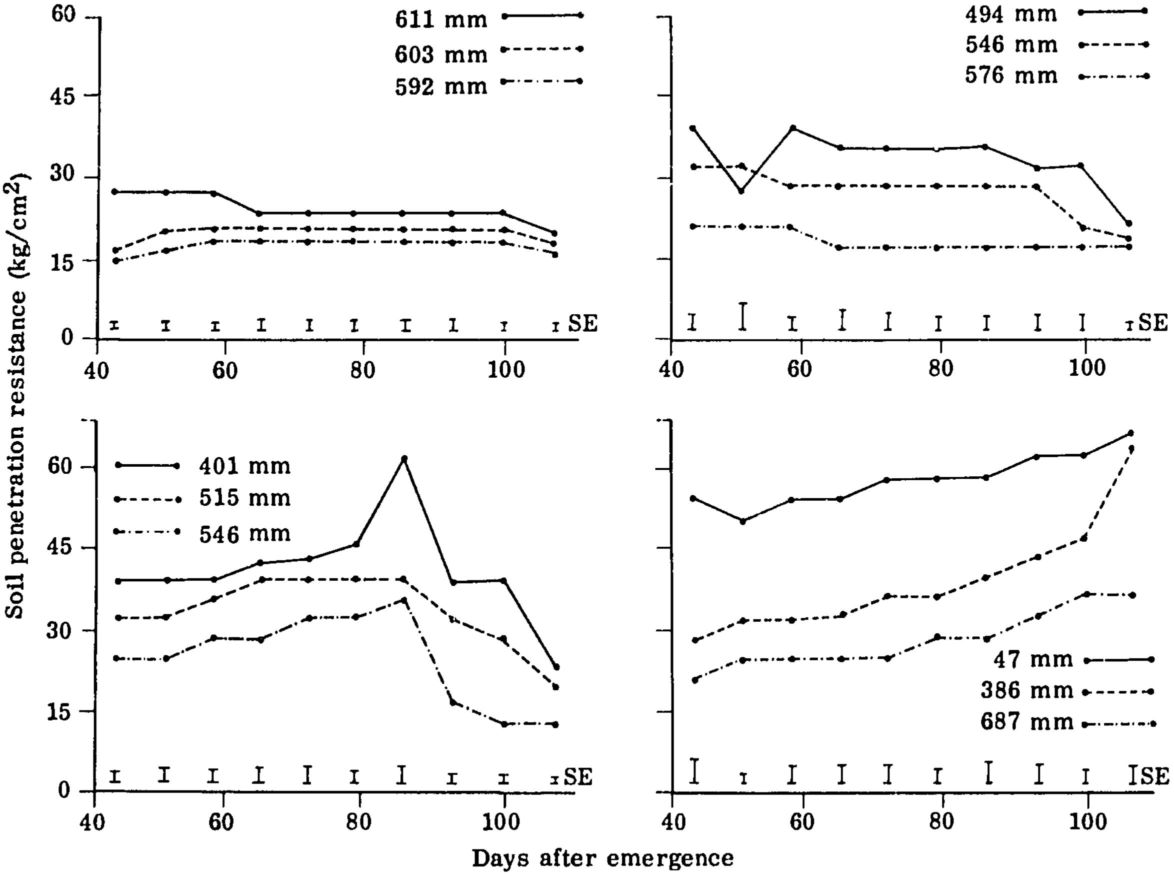


Figure 2. Variation in soil penetration resistance at different ET levels for different treatments, ICRISAT Center, postrainy season 1982-83.

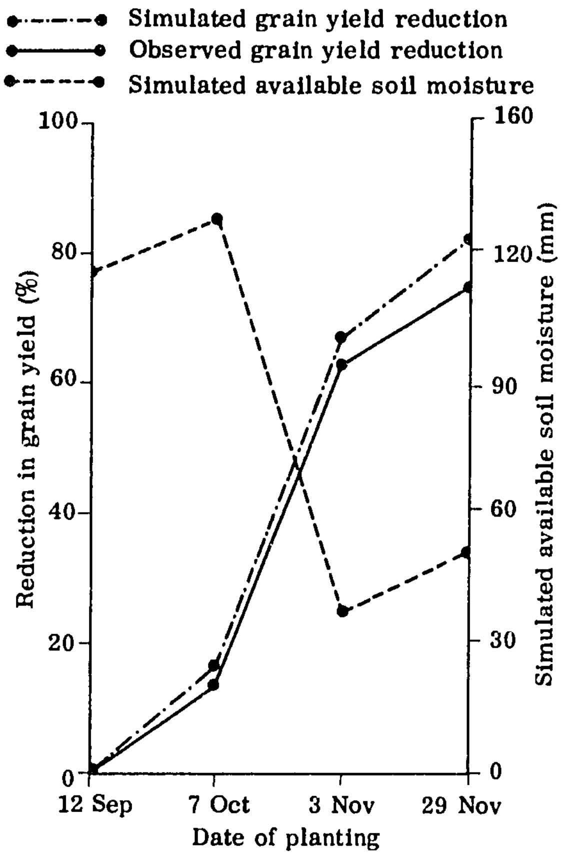


Figure 3. Comparison of simulated and observed reduction in grain yield of sorghum (CSH 1) due to delay in planting under residual moisture, ICRISAT Center, postrainy season 1979-80.

Pearl Millet

A framework for a pearl millet simulation model was developed (Fig. 4) and a preliminary model was assembled. The minimum data set required for this model was identified; field experiments are being conducted.

Phenology. We studied variations in the duration of different phenological stages of 3 pearl millet genotypes (BJ 104, ICH 412 and Ex-Bornu) during cropping seasons from 1981 to 1983. Table 9 shows results from 1982 rainy season, the experiments were conducted with randomized block design and 3 replications. We observed 10 plants from each replication regularly, and a date for a particular phenological event was given when 50% of the plants in all replications reached the event e.g., panicle initiation anthesis and physiological maturity. Analyses of the pooled data obtained from 18 experiments conducted on cv BJ 104 are given in Table 10. The greater variability in the length of the GS_1 growth stage indicates that temperature and daylength variables should be considered to improve its predictability.

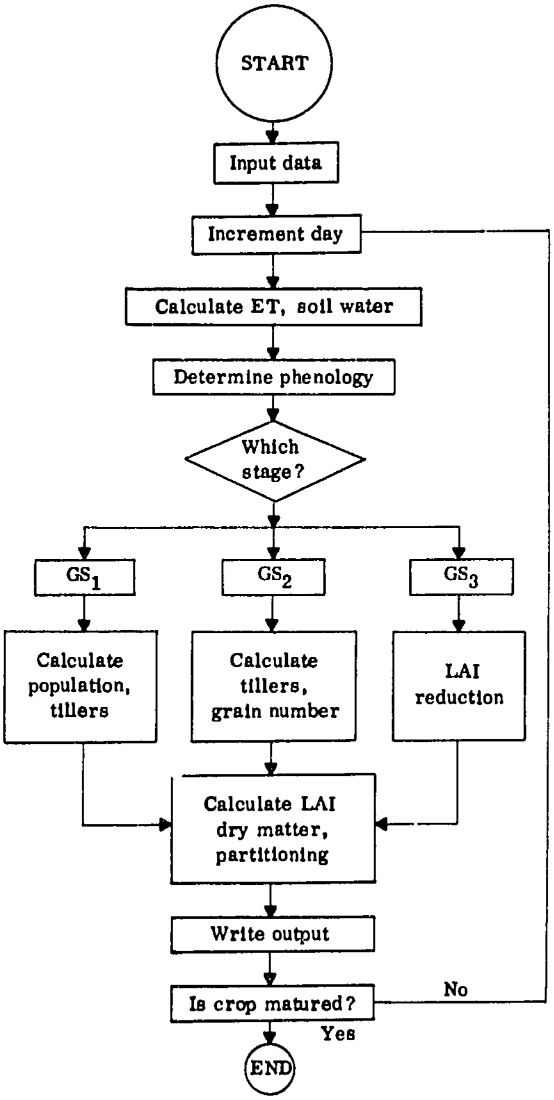


Figure 4. Suggested flow chart for pearl millet simulation model.

Table 9. Duration (days from sowing) of growth stages of 3 genotypes of pearl millet, ICRISAT Center, rainy season 1982.

Growth stage	Genotype BJ 104	ICH 412	Ex-Bornu
Emergence to panicle initiation (GS_1)	15	18	18
Panicle initiation to anthesis (GS_2)	25	36	34
Anthesis to physiological maturity (GS_3)	27	28	27

The growing degree days (GDD) in GS_1 were correlated ($r = 0.85$, $P < 0.05$) with daylength. Earlier studies showed that for sorghum the relationship is linear only above a threshold value (ICRISAT Annual Report 1982, p.286); our preliminary data for millet are in agreement with the relationship obtained for sorghum, with a threshold daylength of about 13.5 hours.

Dry-matter partitioning. Total dry matter and the total partitioned to leaf, culm, head, and grain were periodically estimated throughout the growing season. Proportions of total dry matter partitioned to various plant parts in genotype BJ 104 grown in different seasons varied with growth stages (Table 11).

Tillering. Genotypic variability in contribution of tillers to grain production was observed in 3 genotypes (BJ 104, WC C75, and ICMS 7703) planted on 2 dates in a 1981 rainy season experiment. In the first planting, emergence was 22 June; in the second, 7 July. The number of effective head bearing tillers per main plant was much lower than total tillers produced. The contribution of tillers to grain yield was highest in BJ 104 (Table 12). Number of effective tillers also depends on the date planted. Early planting produced more effective tillers which thus contributed more to total grain yield than with late planting. The contribution of tillers to total grain yield also varied among genotypes. In the early planting, tiller contribution to final yield was 60, 34 and 44% from BJ 104, WC C75, and ICMS 7703, respectively; in the late planting, tiller contributions to total grain yield were 52, 20, and 16%.

Table 10. Variation in lengths of growth stage of pearl millet genotype BJ 104 grown in different seasons at ICRISAT Center (data pooled from 18 experiments).

Growth stage	Max	Min	Mean	SE
	Days			
GS_1	34	13	18	±5
GS_2	36	21	25	±3
GS_3	35	25	30	±3

Table 11. Partitioning (%) of total dry matter at growth stages of pearl millet genotype BJ 104 grown in different seasons on Alfisols and Vertisols ICRISAT Center, 1981, 1982.

Plant part	Panicle initiation	Anthesis	Maturity
Leaf	66±5.7	30±2.9	10±0.0
Culm	34±5.7	54±2.3	30±2.9
Head		16±4.6	60±2.9
Grain			44±1.2

Resource Conservation

Water losses as uncontrolled runoff and soil losses by erosion are presumed to be drastically higher in tropical than temperate regions; however, quantitative data necessary for predicting runoff and erosion potential and evaluating management alternatives are rare for the tropics in general, and particularly for SAT regions. The absence of necessary base-line data curtails development of conservation practices applicable to the SAT and prevents objective evaluation

Table 12. Contribution of tillers and main culm to grain yield (kg/ha) of pearl millet in early and late sowings, ICRISAT Center, rainy season 1981.

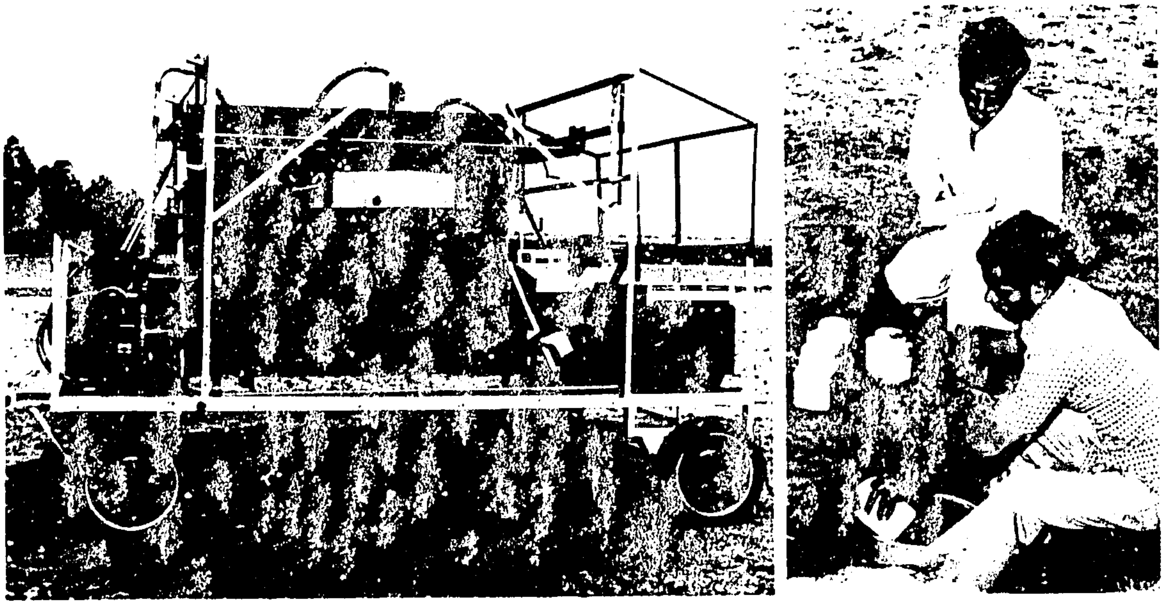
	Early		Late	
Genotype	Main culm	Tiller culm	Main culm	Tiller culm
BJ 104	1560 ±51	2310 ±86	1600 ±71	1760 ±147
WC-C75	1890 ±148	980 ±64	2310 ±142	570 ±103
ICMS 7703	1610 ±124	1280 ±260	2460 ±79	470 ±183

and adaptation of conservation experiences and models developed outside the SAT.

A new subprogram of research on soil and water conservation has been established in the FSRP, to maximize productivity of land through reduced erosion and effective conservation of soil and water resources. Figure 5 shows the research strategy for this subprogram. Disciplinary component research will be conducted on standard runoff plots that allow quantifying runoff and erosion potentials for important SAT soils. Interdisciplinary research with relevant subprograms within and outside FSRP is the intended vehicle for developing effective practices for soil and water conservation and management with particular emphasis on SAT Alfisols. To accelerate the screening of promising management practices and their interrelationships with, and dependence on, soil properties, we will conduct controlled studies on a small scale under simulated rainfall.

Baseline Data for Conservation Planning

When modifying management practices are not imposed, rainfall characteristics, slope-length, and slope-gradient interact to determine runoff and erosion potential on a soil with defined physico-chemical properties. During the relatively above-normal rainfall at ICRISAT Center in 1983, many erosive storms were recorded for fallow Alfisols and Vertisols (Table 13). The data confirm the higher runoff-generating potential of Alfisols where runoff came earlier in the season and more frequently during the season than for the highly-cracking Vertisols.



ICRISAT scientists use this rainfall simulator for controlled studies on runoff and soil erosion. At right, runoff from simulated rainfall is gathered and measured.

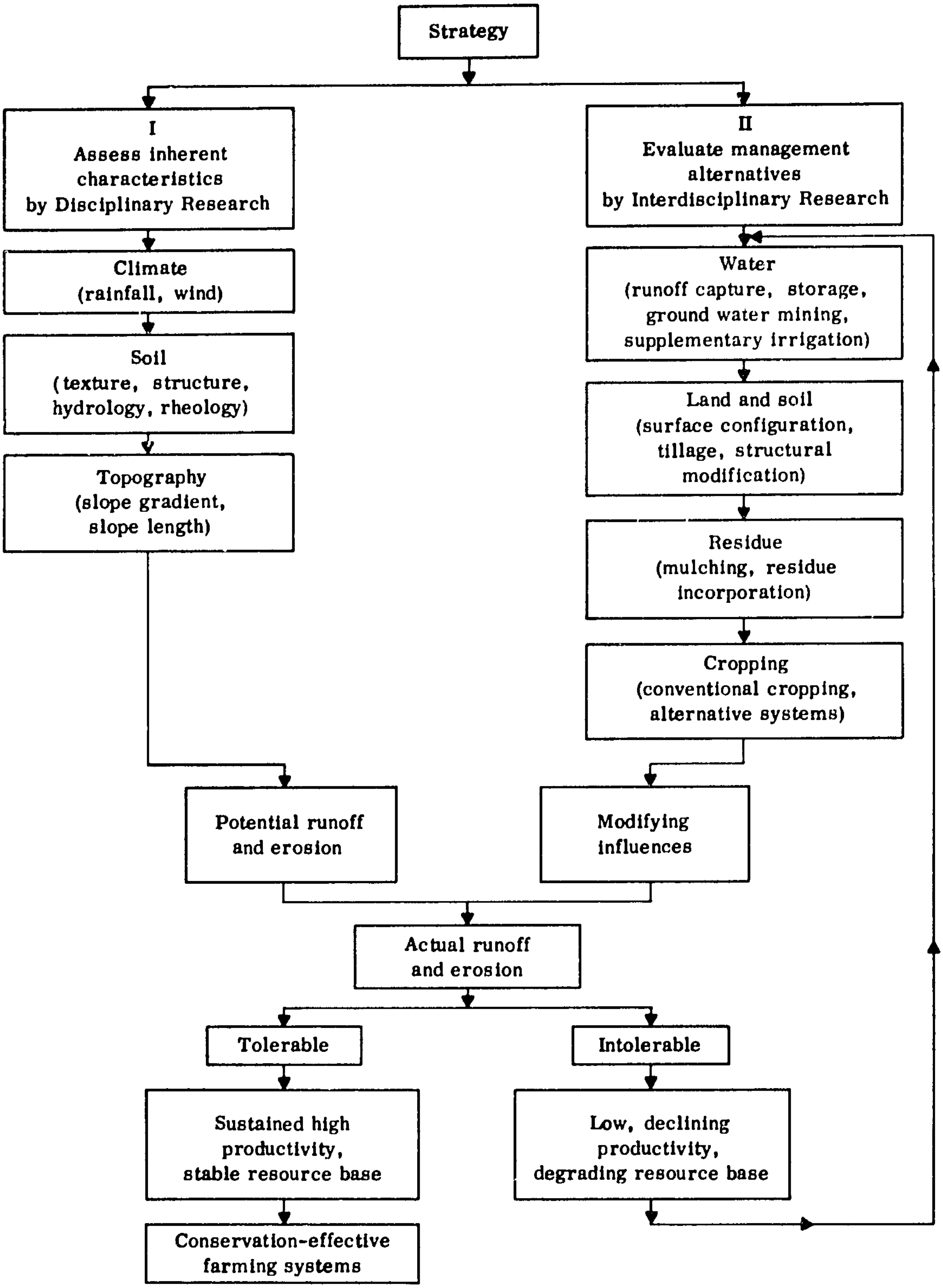


Figure 5. FSRP's strategy of research for soil and water conservation.

Table 13. Monthly breakdown of runoff-producing storms ICRISAT Center, rainy season 1983.

	Initial runoff date	Number of runoff inducing storms in June	July	Aug	Sept	Oct	Total
Alfisols	6 June	5	7	16	12	4	44
Vertisols	14 June	3	1	8	8	2	22

Runoff in Vertisols normally would occur still later when the large cracks that are abundant in them have fully closed. Site preparation for these experiments may have obliterated such cracks from runoff plots. Table 14 shows a breakdown of the storms according to rainfall quantity on both soils. Little difference is noted in runoff trends of the two soils under medium (21-40 mm) and heavy (41-79 mm) storms. However, Alfisols are clearly more susceptible to runoff under the lighter (<20 mm) storms. Indeed, runoff production occured on these soils from storms of as little as 5 mm of rainfall. The runoff and sediment losses of 1983 and their interrelationships with storm and soil characteristics are being analyzed.

Management Alternatives for Conservation Planning

Runoff harvesting potential for SAT Alfisols. Because of the high runoff-generating potential of Alfisols, it may be feasible to harness excess runoff for use in supplemental irrigation in certain situations. In these drought-prone soils, rainfall shortages during the growing season often result in critical soil moisture deficits. Results obtained at ICRISAT from supplemental irrigation have shown clear benefits both during and after the rainy season. Impressive increases in crop yields were obtained by several workers even for high rainfall years. The benefits can be reaped if sufficient runoff occurs and it is effectively stored for later use. The uncertainty of water supply from such systems most limits their feasibility. Seepage and evaporation losses from storage tanks can limit the supply of water when it is most critically needed. We therefore made a quantitative analysis of the usefulness of tanks in meeting supplemental irrigation demands on Alfisols.

Table 14. Erosive storms, ICRISAT Center, 1983 rainy season.

	Rainfall quantity <20 mm	21-40 mm	>41 mm[1]
Alfisols			
Number	27	12	5
% of total	61	27	11
Vertisols			
Number	6	12	4
% of total	27	55	18

1. The heaviest storm was 79 mm.

On Alfisols, even the improved systems of farming lose 20 to 30% of the seasonal rainfall as runoff. The high runoff they produce early in the rainy season provides a more dependable surface water supply throughout much of the season than does runoff from Vertisols (Fig. 6). An analysis of 6 years' data collected from 3 tanks on Alfisol watersheds showed that the tanks consistently contained the water needed for supplemental irrigation during dry spells. Even in 1977, with the least runoff in 9 years (1974-82), the tanks contained more than 35 mm of water (on a catchment-area basis) during periods with high drought probability. A minimum of 50 mm of water was available in the tanks during 80% of the crop growing period each year and 75 mm, during 30% of the period.

Data from a 4th tank on Alfisol watersheds showed clearly that high seepage may seriously hamper tank storage. This 4th tank's average seepage loss was 26 mm/day. A long-term analysis using a previously reported runoff model (modified curve number method, ICRISAT Annual Report 1982 pp 289-291) showed that tanks installed in Alfisols can supply the water needed for supplemental irrigation only when the average seepage rate is less than 15 mm/day. That analysis also showed a 70% probability of having 40 mm of water available for use in July, during periods of high drought probability. The

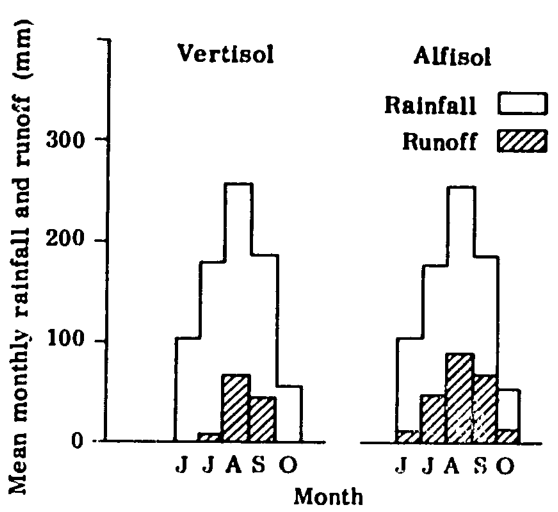


Figure 6. Average monthly rainfall and runoff on Alfisol and Vertisol watersheds with broadbed-and-furrow systems at 0.6% slope, ICRISAT Center, 1975-80.

probability exceeds 92% in August, September, and October.

RUNMOD. The parametric simulation model RUNMOD, described earlier (ICRISAT Annual Report 1981, pp. 244-246) predicts runoff from small agricultural watersheds. Testing in 1981 and 1982, seasons of contrasting rainfall, confirmed that predictions by the model are fairly reliable (Table 15). A limitation of the model is that it must be calibrated at each location.

Land surface configurations for Alfisols: land smoothing and contour bund modification. The prevailing natural landscapes in farmers' fields are generally quite uneven, with many depressions of various sizes. Small surface depressions are obliterated through normal tillage and, thus, are not normally subject to waterlogging. However, large depressions usually remain intact and act as receiving basins for erosional sediments. Once the sediments are deposited, waterlogging often results. In 1981-82, the pearl millet yield from such areas ranged from 8 to 30% less than the average of 1670 kg/ha from upper areas; the pigeonpea yield was 21 to 45% less than the corresponding average of 1070 kg/ha. Both trends were confirmed during 1982-83.

Uneven land surfaces with frequent depressions also prevent proper execution of various agricultural operations, e.g., tillage to, or planting at, a desired depth, which frequently results in poor crop establishment.

Two views of an operation to smooth land on a farmer's field, aimed at avoiding waterlogging. Depressions in Alfisol fields were found to yield 21 to 45% less pigeonpea, and 8 to 30% less pearl millet.

Table 15. Prediction by RUNMOD of runoff from Vertisols at ICRISAT Center, rainy seasons 1981 and 1982.

Land-management system	Year	Rainfall (mm)	Measured runoff (mm)	Computed runoff (mm)
Broadbeds and furrows, cropped	1981	1092	334	323
improved management	1982	521	10	11
Flat, rainy season fallow,	1981	1092	434	434
traditional management	1982	521	4	5

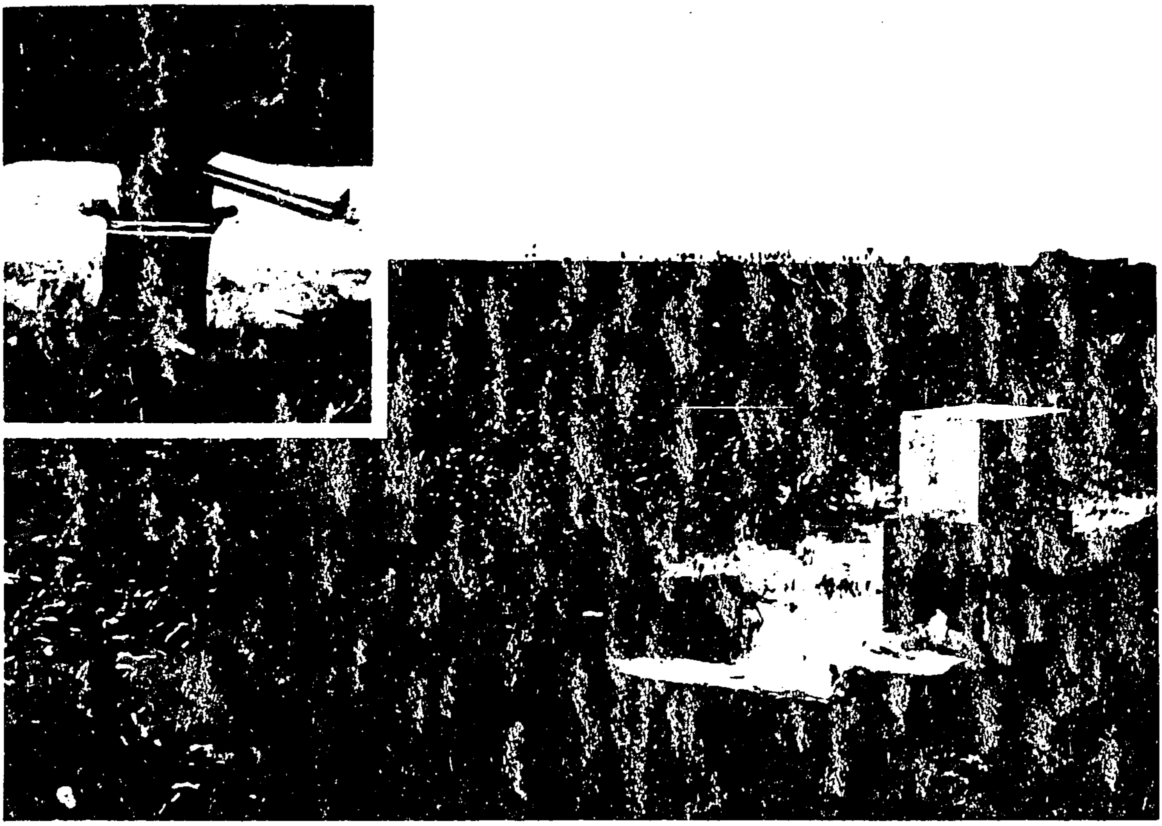
An experiment was conducted in an Alfisol watershed to quantify the benefits of land smoothing and grading on crop establishment and crop yields. Significantly higher germination was recorded for pearl millet and sorghum in the area with proper smoothing and grading than in the area without. During 1982-83, 41% more pearl millet and 26% more sorghum germinated in smoothed than in nonsmoothed areas (plant populations were 204450 vs 145200 for pearl millet, and 170100 vs 135000 for sorghum). These results were attributed to excessive drying of the soil where seeds were placed too shallow, and excessive crust strength for seedlings emerging from seeds placed too deep.

Contour bunding is widely practiced in the SAT, particularly on rainfed Alfisols in India. The system is presumed to reduce soil erosion by dividing long slopes into shorter sections; theoretically the bunds increase the water available for crop use by capturing surface runoff and allowing it ample opportunity to infiltrate into the soil profile. This system was investigated on Alfisols at ICRISAT Center from 1978 to 1982. Results showed that well designed and maintained contour bunds on Alfisols conserve soil and water effectively; for this specific purpose, contour bunds are more efficient than other land management systems. However, the system has certain disadvantages that may outweigh the advantages. The disadvantages include water stagnation and restricted drainage in sizeable areas within fields during the rainy season. In most years crop yields were reduced in areas where water was impounded. The broadbed-and-furrow system produced from 3 to 14% more yield, depending upon rainfall total and pattern; the higher the rainfall, the higher the advantage.

In 1981 an experiment was initiated to refine the design of the contour bunding system to increase crop yields. They were modified by installing gated outlets in lower field sections, land smoothing, and planting on grade instead of on contour, which allowed runoff water to be stored above the bund for a certain period and then released at the desired rate through the gated outlet. Most of the erosional sediments were deposited so that relatively sediment-free water drained through the outlet. Releasing the excess water considerably reduced waterlogging. This system, when compared with alternative land management systems on operational scale during 1981-83, consistently produced the high-

Table 16. Grain yield, runoff, and soil loss from different land-management systems, Alfisol watersheds, ICRISAT Center, 1982-83.

Land-management system	Crop	Grain yield (kg/ha)	Runoff (mm)	Soil loss (t/ha)
Broadbed-and-furrow	Sorghum/	2830	195	3.62
	pigeonpea	820		
	Pearl millet/	2210		
	pigeonpea	900		
Contour bund	Sorghum/	2690	42	0.49
	pigeonpea	700		
	Pearl millet/	2200		
	pigeonpea	870		
Modified contour bund	Sorghum/	3040	80	0.93
	pigeonpea	880		
	Pearl millet/	2620		
	pigeonpea	920		
Traditional	Sorghum/	360	181	3.83
	pigeonpea	210		
	Pearl millet/	490		
	pigeonpea	270		



Contour bunding, as traditionally practiced in the SAT, restricts drainage and reduces yields. Gated outlets (inset) in lower sections of the field help conserve both soil and water, and improve yields.

est crop yields while still providing adequate control of runoff and soil loss. The comparative performance of this and other systems during the normal rainfall year of 1982-83 is shown in Table 16.

Traditional Runoff-Storage Tanks

Small reservoirs, better known locally as tanks, are one type of traditional water-harvesting structure in SAT India. Associated with each traditional small tank are its catchment and command areas (Fig. 7). Two representative tanks and their irrigation systems have been studied by the FSRP in villages under study by the Economics Program in the Alfisol area of Mahboobnagar district, Andhra Pradesh. The main aim of the study was to characterize the tanks, and their overall efficiency for irrigation. The tanks at Aurepalle and Dokur are described below.

Aurepalle village tank. Aurepalle village receives an average annual rainfall of 710 mm; its main crops are sorghum, castor, pearl millet, pigeonpea, and paddy rice. The sole village tank occupies 12 ha with storage capacity of 18 ha cm^3 ($1.8 \times 105m^3$) and a maximum depth of 3 m. The catchment area is 3 m. Permeability of the reservoir bed is quite low, about 0.37 mm/day, apparently as a result of heavy silting over the years. However, the permeability of the bund is much higher, about 31.5 mm/day at 0 to 0.5 m depth, and about 3900 mm/day at 0.5 to 1 mm depth. The command area's average slope is 1%. The soils are sandy clay loams to sandy loams with

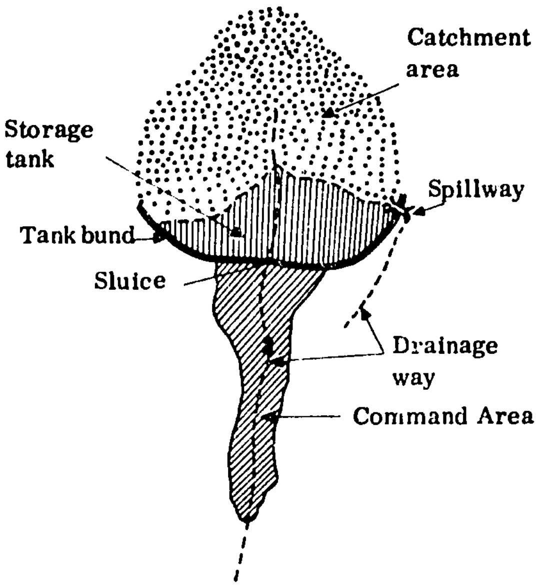


Figure 7. A hypothetical sketch of a traditional small tank irrigation system.

depths from 60 to 120 cm. The land is divided into very small plots (0.13 to 3.96 ha fields) owned by 16 farmers. The predominant crop in the command area is paddy rice.

Dokur village tank. Average annual rainfall in Dokur village is 710 mm; the crops are similar to those of Aurepalle. The selected tank in this village has a storage capacity of 8.5 ha m^3. Its area is 9.3 ha; the command area is 13.2 ha. It receives water from a 215-ha catchment and from spills of other tanks. Permeability of the tank bed is quite low, about 0.2 mm/day, but it is about 2.5 mm/day for the bund, in the 0 to 0.5 m depth layer, and about 700 mm/day in the 0.5 to 1 m depth layer. Soils of the command area are 60 to 120 cm deep, and vary from sandy loams to loamy sands. The general slope in the command area is 1.1%. Land in the command area is owned by 16 farmers whose holdings range from 0.07 to 2.42 ha, and paddy rice is the predominant crop.

Water use by crops in the command area. We estimated inputs and outputs of water for various parts of the system. A staff gauge and a USDA Class A evaporation pan were installed in each tank to estimate changes in storage and daily evaporation from the tanks. Seepage losses were estimated by balancing the input water, evaporation, and release volume. Benchmarks were established on all the wells in the command area of the respective tanks to monitor daily water-table fluctuations. To determine the contribution of wells to the irrigation water applied to individual plots, we recorded water removed from the wells. To estimate evapotranspiration from the rice crop, we installed a USDA Class A evaporation pan in each command area. Crop yields in the farmers' fields were estimated by sampling small areas.

From these data we determined the effectiveness of the water-storage systems by calculating the water-use efficiency (WUE) for 3 categories of water:

1. System-WUE, which includes all sources of water.
2. Project-WUE, which excludes water lost by seepage.
3. Potential-WUE, which considers only evapotranspiration use by the crop.

The results (Table 17) obtained show that the differences between Potential-WUE and Project-WUE were always much greater than the differences between the Project-WUE and System-WUE, indicating clearly that losses by evaporation and seepage from the tank are much less important than losses after water leaves the tank sluice-gate. We infer that the major sources of loss are seepage from paddy fields and from water-delivery system.

Tank optimization. Designing a runoff collection, storage, and utilization system requires knowledge of:

1. Tank location
2. Tank volume
3. Tank dimensions after its volume has been determined

The size of the tank can be determined by the catchment area available for producing runoff and/or the limited area suitable for irrigation, termed a "constrained case." When neither the

Table 17. Water-use efficiencies (kg/ha per cm) of rice under traditional tank irrigation systems at Aurepalle and Dokur villages, Mahboobnagar district, India.

		Aurepalle			Dokur[1]		
Year	Season	WUE system	WUE project	WUE potential	WUE system	WUE project	WUE potential
1977-78	Rainy	-[2]	-	-	17	22	91
	Postrainy	-	-	-	TE[3]	TE	-
1978-79	Rainy	11	16	37	15	19	145
	Postrainy	13	18	35	TE	TE	
1979-80	Rainy	19	20	79	20	31	128
	Postrainy	20	21	79	-	32	145

1. In Dokur village, irrigation was applied solely from wells during 1979-80 post-monsoon season.
2. No data available.
3. TE = Tank empty.

catchment area nor the irrigable area limits tank size, it is an "unconstrained case."

A nonlinear optimization model was developed for designing small runoff storage structures under "constrained" and "unconstrained" situations. Input data for this model are: depth of irrigation to be applied, size and shape of catchment areas, runoff volume, seepage and evaporation rates, unit cost of irrigation application, cost of land, life of reservoir, price of the farm produce, and irrigation efficiency.

The flow chart for this model is given in Figure 8.

Intercropping Studies

Millet vs Sorghum as an Intercrop with Pigeonpea

Earlier agronomic studies (ICRISAT Annual Report, 1981, pp.205-207) indicated that early-maturing, short cereal genotypes were best for the cereal/pigeonpea intercropping system because they were least competitive with pigeonpeas. We found millet was less competitive than sorghum probably because the millet genotypes we examined matured earlier than the sorghums. However, there have been some suggestions that millet competes strongly as an intercrop with pigeonpea.

The relative competitiveness of millet BK 560 and sorghum CSH 5 in a 2 cereal:1 pigeonpea row arrangement was examined in detail on a Vertisol using a randomized block design with three replications. To separate the effects of differences in maturity of the two cereals, sorghum was either removed when millet was harvested (80 days) or at normal sorghum harvest (104 days). Two N rates, 0 and 80 kg N/ha, were applied to the cereal; these caused two different rates of cereal growth thus bringing about different intensities of competition on the pigeonpea.

Cereal growth was good; yields for sole crops with 80 kg N/ha were 2800 kg/ha grain (8730 kg/ha TDM) for millet and 5820 kg/ha grain (15070 kg/ha TDM) for sorghum. Intercropping did not reduce millet yields at either nitrogen rate; sorghum yield was not reduced with high N, but without N it was only 71% of the sole crop. Pigeonpea TDM was better when no N was applied to the cereal (Fig. 9) and it was reduced more by sorghum than by millet. Without N the difference between effects of the 2 cereals on the pigeonpea intercrop was small and not reflected in the final pigeonpea grain yield. At 80 kg N/ha for sorghum or millet, sorghum was much more competitive than millet and the effects on pigeonpea growth were maintained until final harvest; pigeonpea grain yield was only 73% of its sole-crop yield with sorghum

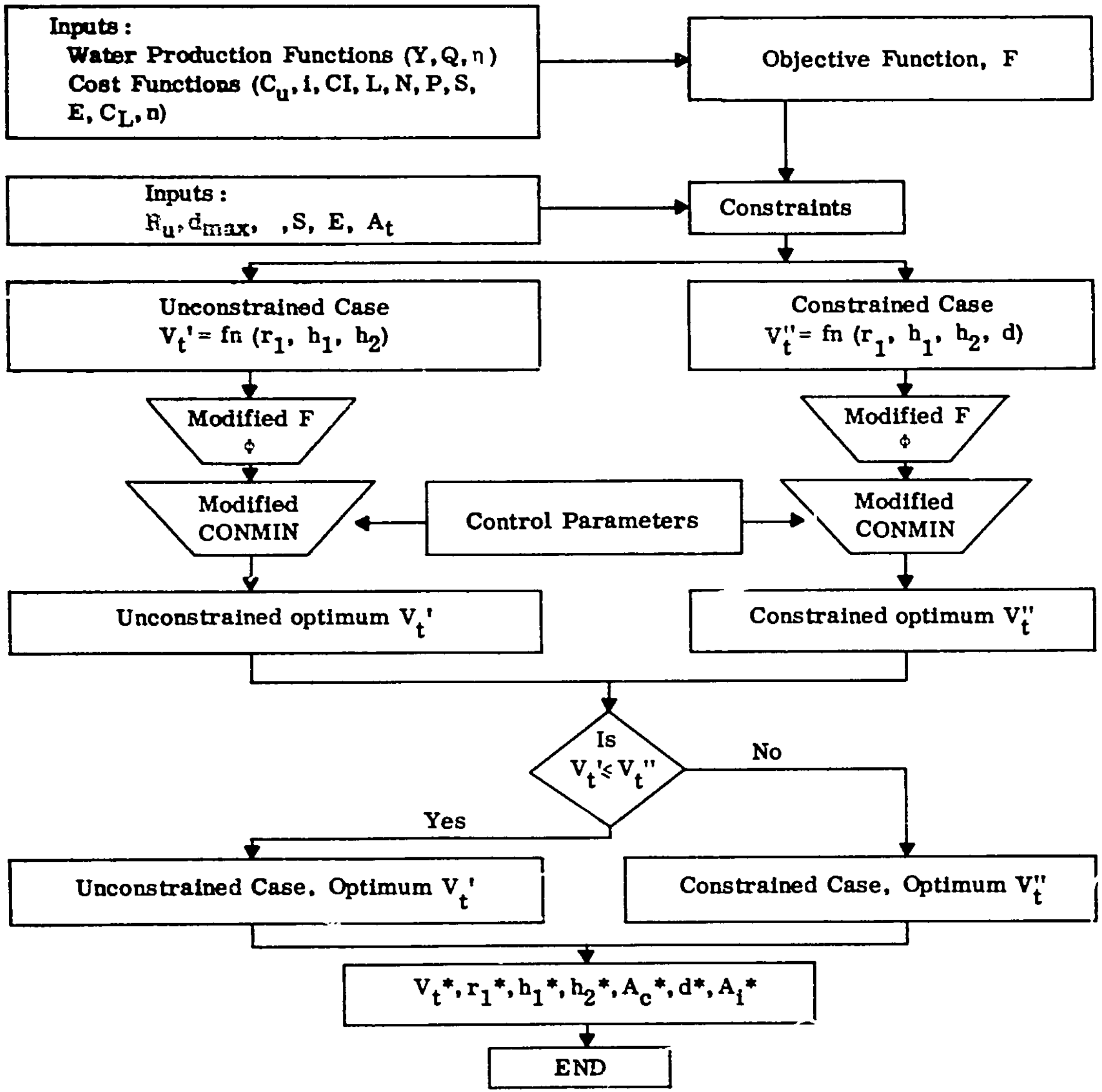


Figure 8. Flow chart of the tank system optimization model.

A_c^*	optimum catchment area
A_i^*	optimum command area
A_t	total area of catchment
CI	fixed cost of inputs for crop production
C_L	cost of land occupied by a small tank
C_u	unit cost of construction of a tank
d^*	optimum distance of a small tank from the mouth of a catchment
d	distance of a small tank from the mouth of a catchment
d_{max}	maximum length of catchment
E	average daily evaporation rate
h_1	depth of a small tank below ground level
h_1^*	optimum depth of a small tank below ground level
h_2	height of a small tank above ground level
h_2^*	optimum height of a small tank above ground level
i	annual discount rate
L	cost of labor for each irrigation
N	number of irrigations
n	slope of a bund
P	market price of a crop
Q	water use of a crop
R_u	seasonal runoff expected
r_1	radius of a tank at ground level
r_1^*	optimum radius of a tank at ground level
S	average daily seepage rate
V_t^*	optimum storage capacity of a small tank
V_t'	unconstrained storage capacity of a small tank
V_t''	constrained storage capacity of a small tank
Y	grain yield of a crop
η	project irrigation efficiency
CONMIN	Constraint minimization Fletcher-Powell algorithm
Φ	modified fraction (F)

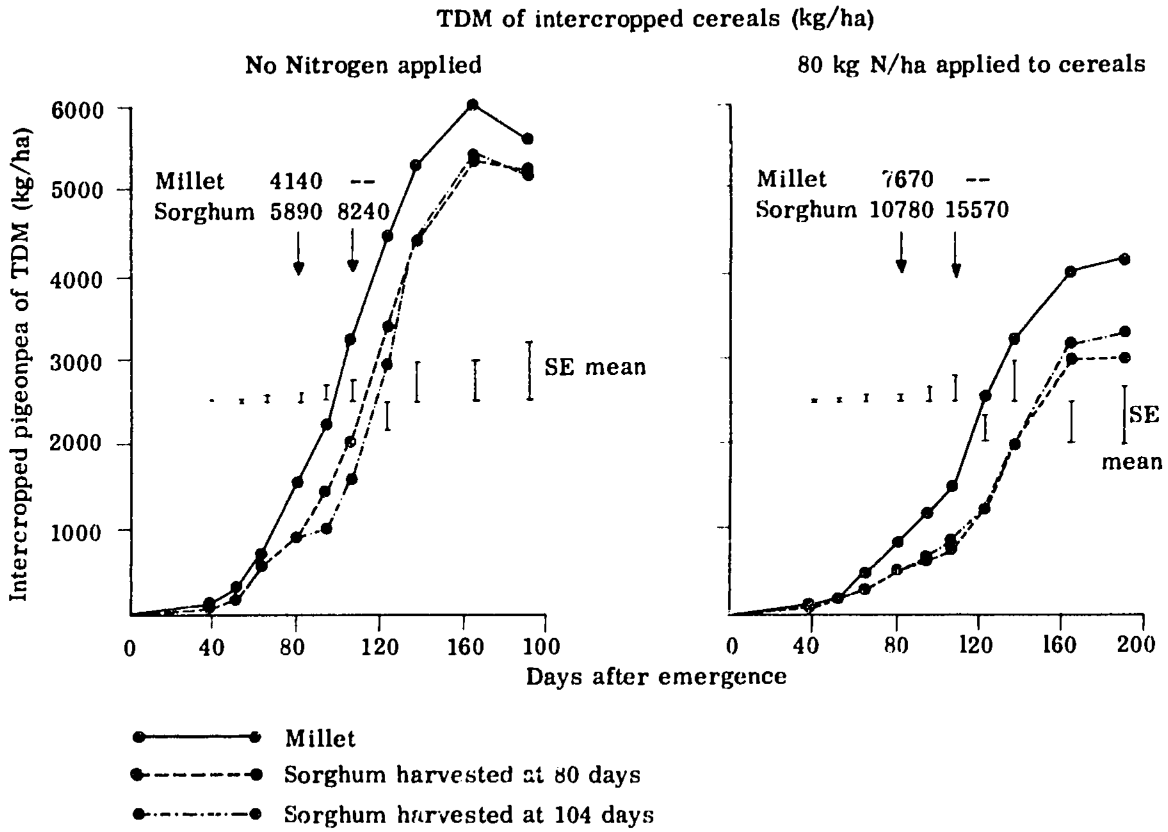


Figure 9. Effects of intensity, duration, and type of cereal competition on dry-matter production of pigeonpea intercropped with millet, and sorghum harvested on two different dates, ICRISAT Center.

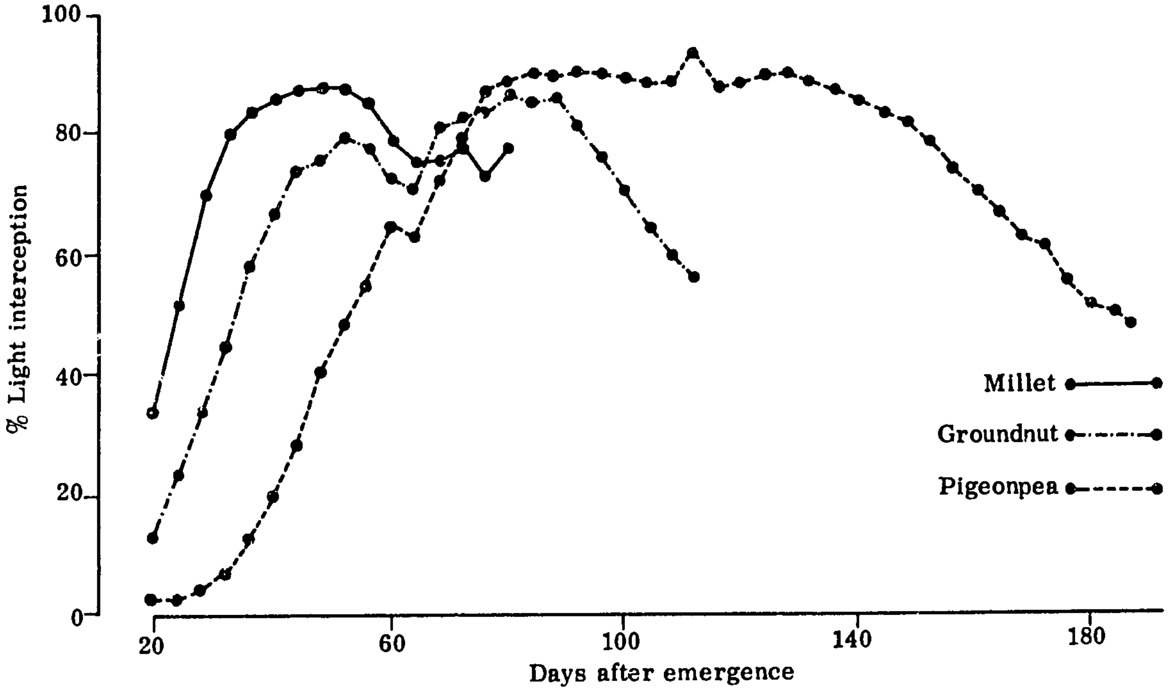
compared with 97% with millet. In this experiment millet was clearly better than sorghum in a cereal/pigeonpea intercropping system.

Surprisingly, removing the sorghum at millet harvest did not reduce the final effects of sorghum competition. Apparently pigeonpea yield was determined more by the intensity of early competition than by the duration of the cereal intercrop.

Three-Component Intercrop: Millet/Groundnut/Pigeonpea

In 1982 we reported very large yield advantages from a groundnut/pigeonpea intercrop on Alfisols (ICRISAT Annual Report 1982, pp.272-273). This year we added an early millet as a 3rd component crop to see if we could further improve complementarity in time among the component crops and, thus, increase yield advantages. Temporal differences among the crops are illustrated by light interception patterns of the sole crops (Fig. 10). As sole crops, they achieved a given degree of canopy cover in this order; millet 10 to 15 days earlier than groundnut, and groundnut 15 to 20 days earlier than pigeonpea.

The 2-component intercrops gave results similar to those in previous studies. For millet/groundnut in a 1:3 row arrangement, light interception in the early stages was intermediate between the 2 sole crops; later, groundnut ensured some light interception after the millet harvest. Thus, millet/groundnut intercropping gave a grain yield advantage of 31% over sole cropping (59% millet and 72% groundnut). In



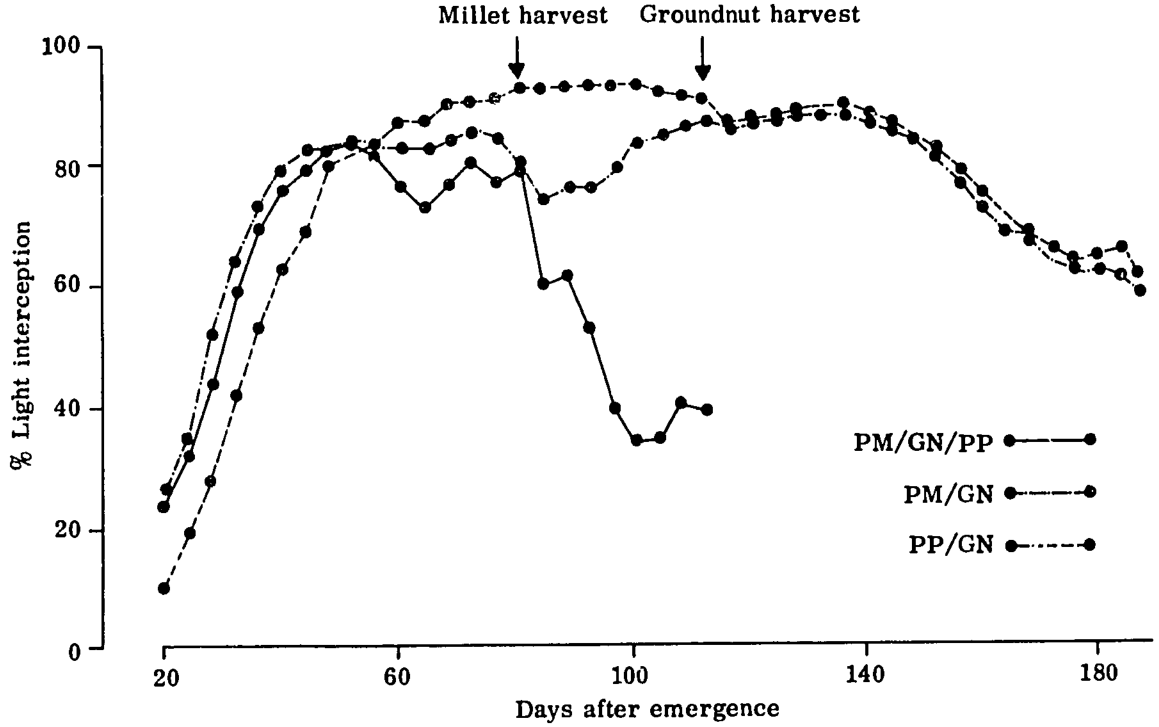


Figure 10. Light interception by sole crops of pearl millet, pigeonpea, and groundnut (above) and pearl millet/groundnut, pigeonpea/groundnut, and pearl millet/pigeonpea/groundnut intercrops (below).

comparison, groundnut/pigeonpea developed the canopy more slowly in the early stages but maintained high interception to the end of the season. Grain yield advantage was 52% (70% groundnut and 82% pigeonpea). The 3-component intercrop achieved some advantages of both 2-component intercrop: early interception was as good as with millet/groundnut and late interception as good as with groundnut/pigeonpea, but there was some sacrifice in the intermediate stages after millet harvest. Yield advantage was 59%, only a little higher than from groundnut/pigeonpea, but compared with this 2-component intercrop, a large additional millet yield was achieved at the expense of groundnut (62% millet, 21% groundnut, 76% pigeonpea). Choice of these two options would depend on a farmer's crop requirements. In cash value, the groundnut/pigeonpea gave a slightly greater return than the 3-component intercrop.

The experiment gave little further information on what type of leaf canopy might improve conversion of intercepted light by leaf canopies of intercrops. Millet/groundnut was 28% more efficient, which was similar to earlier findings. The 3-component intercrop followed the pattern of last year's groundnut/pigeonpea with no improvement in efficiency. However, sole millet grown at the same population and spacing as in the 1:3 millet/groundnut improved efficiency by 19%. The better light regime on lower millet leaves could partly explain the intercropping advantages, perhaps because these leaves maintain photosynthetic efficiency longer.

Nutrients

Nitrogen Fertilization Strategies

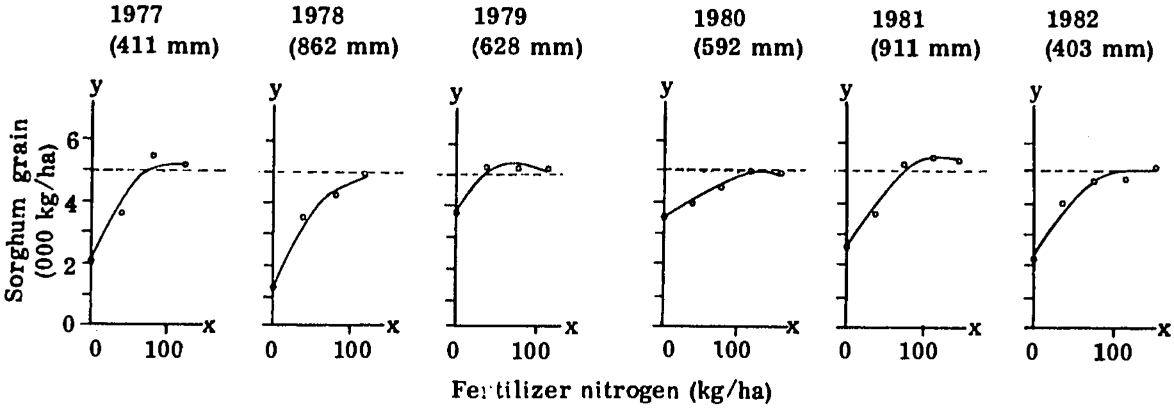
It is commonly assumed that lack of water limits crop productivity in the SAT much more than lack of nutrients. Although those Vertisols in southern and central India which receive more rainfall than ICRISAT Center have been classified as having dependable rainfall for grain production by a rainy season crop, we do not have corresponding data on the reliability of cereal responses to applied N. Such data are essential when considering fertilizer strategies, as there is high variability in rainfall across the SAT. It is important to develop a better understanding of the reliability of responses.

SAT farmers appear to be reluctant to invest in fertilizer N if the crop responses are unprofitable even in a small proportion of seasons, although excellent profits would be obtained in most seasons. To determine a basis for understanding the benefits and risks faced by SAT farmers, we need information on crops' responsiveness to fertilizer over several seasons. We have compiled data from experiments, conducted in a consistent manner from year to year, for both Vertisols and Alfisols at ICRISAT Center.

Sole sorghum on deep Vertisols. Grain yields of rainy-season sorghum, CSH 6, grown in small-plot research experiments, exceeded the very satisfactory 5000 kg/ha in each of the 6 rainy seasons from 1977 to 1982, provided adequate N was applied (Fig. 11). In the absence of added N, grain yields were as low as 1300 kg/ha. Seasonal rainfall (planting to harvest) varied from 474 mm to 907 mm; this did not markedly affect yields, nor were the responses of yields without N closely related to rainfall. For example, the two seasons in which responses were highest (1977 and 1978) were those with extremes in seasonal rainfall.

Seasonal rainfall ranged from moderately low (403 mm) to high (911 mm), when compared with the average (630 mm) taking 1 June to 30 September as the appropriate season. However, 1979 was a particularly droughty season, with high evaporation rates and several prolonged periods without rainfall prior to anthesis. It was one of the harsher seasons in this area, although the total seasonal rainfall was average. Sorghum on Alfisols at ICRISAT Center wilted severely in 1979. Outside the Center, crop failures were common. Yet, dry-sown, rainy-season hybrid sorghum on our deep Vertisol still achieved a maximum yield of 5000 kg/ha.

We conclude that variations in nutrient supply are much more important than variability in seasonal rainfall in determining the yield of



Regression equations:

1977: $y = 1920 + 62.4x - 0.28x^2$ $R = 0.81$ rse = 1063
1978: $y = 1310 + 53.3x - 0.19x^2$ $R = 0.97$ rse = 386
1979: $y = 3920 + 37.8x - 0.23x^2$ $R = 0.92$ rse = 280
1980: $y = 3340 + 19.6x - 0.59x^2$ $R = 0.99$ rse = 123
1981: $y = 2580 + 44.3x - 0.17x^2$ $R = 0.97$ rse = 358
1982: $y = 2340 + 40.8x - 0.15x^2$ $R = 0.91$ rse = 510

Figure 11. Response of sole-cropped hybrid sorghum (CSH 6) to applied N on deep Vertisols, ICRISAT Center, rainy seasons 1977-82. Seasonal rainfall given in parentheses after year.

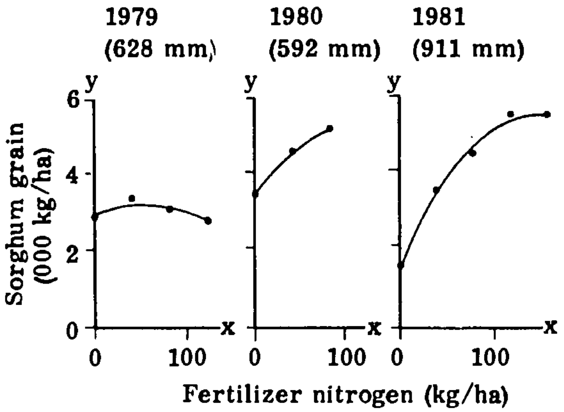
improved rainy season sorghum cultivars on Vertisols at ICRISAT Center. That does not imply that fertilizer-N should be applied every year. The surprisingly high yields achieved in some years without added N indicate the need for studies to identify the factors involved, so responsive situations can be predicted with some degree of certainty.

ICRISAT Center is located at the dry margin of the area where rainfall is dependable for rainy-season sorghum on deep Vertisols. We may therefore assume that the presently-mapped dependable area also demarcates the area where nutrients, especially nitrogen, could be much more important determinants of rainy-season sorghum yields on deep Vertisols than variations in seasonal rainfall.

Sole sorghum on Alfisols. Although our data base for rainy-season sorghum hybrid CSH 6 is smaller for Alfisols than for deep Vertisols, the maxima of the yield response curves are more variable (Fig. 12). In the moderate and high seasonal rainfall years (1980 and 1981), maximum yields exceeded 5000 kg grain/ha. But, in droughty 1979, the maximum was only 3400 kg/ha and yields were further depressed when applied N exceeded 40 kg/ha; nevertheless a small, but economic, response was obtained to the first increment of applied N. We conclude that maximum yields (when N supplies are adequate) will vary more on Alfisols than on Vertisols. Clearly, maximum yields are determined by both rainfall and nutrient supplies.

The critical factor determining differences between Vertisols and Alfisols in responsiveness to added N is the moisture-holding capacity of the soil. Alfisols store insufficient moisture to maintain plant growth during droughty, rainless periods, especially when growth is stimulated by addition of fertilizer N.

The Alfisols on which these experiments were conducted have at least moderate depth with moderate to high clay content (15-30%). Many



Regression equations:

$$1979:\ y = 2950 + 12.9x - 0.11x^2$$
$$R = 0.51 \qquad rse=351$$
$$1980:\ y = 3590 + 36.2x - 0.18x^2$$
$$R = 0.90 \qquad rse=400$$
$$1981:\ y = 1620 + 54.9x - 0.18x^2$$
$$R = 0.99 \qquad rse=187$$

Figure 12. Response of sole-cropped sorghum (CSH 6) to fertilizer-N on Alfisols, ICRISAT Center, rainy seasons 1979-81. Seasonal rainfall (sowing-harvest) given in parentheses after each year.

other Alfisols and related soils in southern India are shallower or have a lower clay content. Alfisols which receive less total rainfall than those at ICRISAT Center would appear to have higher risks associated with applications of fertilizer N. The critical value of seasonal rainfall, above which soil moisture supply is not a major factor limiting maximum yields, is higher for Alfisols than for Vertisols.

Efficiency of Fertilizer Nitrogen

Continuing earlier work in the IFDC/ICRISAT collaborative project, we are characterizing various aspects of nitrogen use on the benchmark soils at ICRISAT Center. Efforts previously focused on obtaining initial information on the fate and efficiency of nitrogen, mainly urea, applied to sole sorghum on a Vertisol and an Alfisol. We now are attempting to broaden the data base by examining diverse sources of N applied to different cropping systems. The fate of applied nitrogen is being examined using ^{15}N-labeled fertilizer. The ^{15}N analyses are in progress, so only agronomic results are reported here.

Rainy-season sorghum on deep Vertisols. We compared the effectiveness of different sources of N, applied at 60 kg N/ha, to rainy-season sorghum (CSH 6). N was applied in bands below the soil surface, half at seeding (dry) and half 4 weeks later. These treatments were part of a larger experiment with four replicates (Table 18).

Table 18. Effect of N source, and methods of applying urea, on response of grain and stalk of CSH 6 sorghum to 60 kg N/ha, Vertisol, ICRISAT Center, rainy season 1982.

Treatment			Yield	
	Method of application			
Source of N	Time	Placement	Grain	Stalk
Nil (control)	-	-	2870	4670
Nitrophosphate/urea[1]	Split[2]	Band[3]	5490	6780
Potassium nitrate	Split	Band	5390	6910
Ammonium nitrate	Split	Band	5540	6990
Urea supergranule[4]	Basal[5]	Band	5530	6920
Urea	Split	Band	5250	6760
Urea	Split	B-cast[6]	4620	6160
Urea	Basal	Band	5290	6160
Urea	Basal	B-cast	5650	6350
Urea supergranule	Delay[7]	Band	5220	6760
Urea supergranule/urea[8]	Split	Band	5200	5630
SE			±180	±283

1. 30 kg N/ha applied as nitro phosphate (20-20-0), basal 30 kg N/ha applied as urea by side dressing, 4 weeks after seeding (AS).
2. Split applications: 30 kg N/ha at seeding, 30 kg N/ha as side-dressing 4 weeks AS.
3. Band: fertilizer placed in a band, 5 cm out from and 5 cm below seed row.
4. Urea supergranlues all placed in a band, 1 granule between two plants.
5. Basal: all N (60 kg/ha) applied at seeding.
6. B-cast: fertilizer broadcast uniformly on soil surface.
7. Delay: all applied 2 weeks AS.
8. Urea supergranule (30 kg N/ha) applied at seeding, normal urea pellets (30 kg N/ha) as a side-dressing 4 weeks AS.

Rainfall between sowing and harvesting was adequate (510 mm), and generally well distributed except for a dry period in late August.

The N sources used were equally effective; all increased grain yields to about twice the control yield of 2870 kg grain/ha (Table 18). The slope of the response curve of more than 45 kg grain/kg added N indicates that all forms of N applied were used efficiently, and that N losses were small, although ^{15}N recovery data are needed to confirm this finding.

Method of applying urea to sorghum. Results were not consistent in our previous studies on application methods (ICRISAT Annual Reports 1981, pp. 231-233; 1982, pp. 247-250). In the very wet 1981 season the split-band application increased uptake to 55% from the low value of 30% for a broadcast application at seeding. The split-band method also reduced N losses to less than 7% compared to 25% for broadcast. But in 1980, split-banding did not improve efficiency. We have, therefore, continued studies on this application method.

Our results in 1982 provide further contrasts (Table 18). N applied in bands (basal or split) gave no significant advantage over N broadcast as a basal application. But, N broadcast in split applications gave significantly lower yields than the banded treatments or the broadcast-basal treatment. We attributed this to the dry period which occurred after the 2nd application had been broadcast on wet soil. We suspect losses by ammonia volatilization. ^{15}N analyses should provide some verification.

Table 19. Effect of nitrogen fertilization and fallowing on grain yields of rainy-season sorghum (CSH 6) and postrainy-season safflower (cv Manjira); deep Vertisol, 1982.

Rainy season			Postrainy-season safflower yield (kg/ha)		
Cropping system	N (kg/ha)	Sorghum yield (kg/ha)	N (kg/ha)		
			0	30	60
Sorghum	0	3550	-	-	-
	60	4470	-	-	-
Fallow	0	-	1470	-	1960
Sorghum	0	3720	620	-	-
	30	4710	-	1000	-
	60	4890	720	-	-
	60	5180	-	1050	-
	90	5290	860	-	-
SE		±180		±90	

Deep Vertisols: effects of residual N and fallowing. The development of a double-cropping system for deep Vertisols to replace the traditional single crop in the postrainy season, is an attempt to fully utilize the natural water resources of these soils. However, little attention has been given to a number of fertility aspects; especially important are residual effects of fertilizers applied to rainy-season or postrainy-season crops, and the effect that the introduction of rainy-season cropping has on the fertilizer needs of postrainy-season crops.

We are examining the effects of cropping and fertilization in rainy and postrainy seasons, and subsequent residual effects in each of 2 successive years. We are using sorghum in the rainy season and safflower in the postrainy season. The treatments (see Table 19) were arranged in a randomized block design with four replicates. Preliminary results are available for the first year.

Growing sorghum in the rainy season, thus eliminating fallowing, significantly reduced safflower yields, from 1470 to 620 kg/ha (Table 19). Safflower grown after a rainy season fallow responded significantly ($P<0.05$) to 60 kg N/ha, increasing grain yield to 1960 kg/ha.

The residual effects of nitrogen applied to the rainy-season sorghum on safflower, grown in the postrainy season, were not statistically significant ($P<0.05$) as shown by safflower yields in Table 19. N applied directly to safflower caused much larger, statistically significant, responses ($P<0.05$).

The preliminary results clearly indicate that successful double cropping on deep Vertisols will require additional nutrient inputs for both the rainy-season and postrainy-season crops.

Alfisols: millet/groundnut intercrop. Further studies with ^{15}N are being conducted to follow earlier work on the millet/groundnut intercrop (ICRISAT Annual Report 1982, pp. 255-258). These involve more detailed investigations to determine whether fertilizer applied to a single row of millet is readily taken up by adjacent rows of groundnut. We are also investigating whether altering spatial management of the intercrop rows influences fertilizer efficiency. In particular, we are examining whether fertilizer applied between the two millet rows of millet/groundnut in a 2:6 row arrangement is more efficient than when N is applied to the single row of millet in the 1:3 row arrangement. ^{15}N-labeled fertilizer is being used to measure efficiency.

The agronomic yield results indicated little response to N, but the ^{15}N data should provide useful information on crop geometry effects on N uptake.

Fertilizer Placement

Placing seed and fertilizer about 5 cm apart in the soil is considered desirable to minimize the effects of a high concentration of fertilizer on germinating seeds. Because the soil-moisture content of Vertisols at field capacity is high, we expected that fertilizer concentrations in the soil water should be lower than in light-textured soils, where deleterious effects result from applying fertilizer in the seed row. To study effects of fertilizer placement, we conducted an experiment using a split-split plot design. It consisted of 3 different fertilizer placements in relation to the seed row in main plots, 3 different types of compound fertilizers as sources of N in subplots, and 2 basal application rates of N at seeding in sub-sub-plots. There were 4 replicates.

The 3 methods of placing fertilizer were (1) all in the seed row, (2) all 4 cm to one side and 4 cm below the seed row, (3) half in the seed row and half (as urea) 10 cm to one side and 10 cm below the seed row. Three fertilizer sources provided N:P:K at 18:20:0 (diammonium phosphate), 28:12:0 (ammonium phosphate), and 20:8:0 (nitrophosphate). The two N rates, both applied at seeding, were 40 and 80 kg N/ha.

The animal-drawn wheeled tool carrier (WTC) was used for all field operations. For planting and fertilizer application, we used the 4-row planter. Each plot (6 m × 4.5 m) had 9 rows of sorghum. Special furrow openers were constructed to obtain the desired placement of fertilizer and seed. The fertilizer drill was calibrated to deliver the planned rate, within a 10% margin. Dry planting on the entire experimental area was completed by 10 June, 1982.

Table 20. Effect of fertilizer placement on plant height of rainy-season sorghum (CSH 6) at 8 weeks after emergence; Vertisol, ICRISAT Center 1983.

Method of placement	Plant height (cm)
Within seed row	119
Away from seed row[1]	126
Combined[2]	124
SE	±6.2

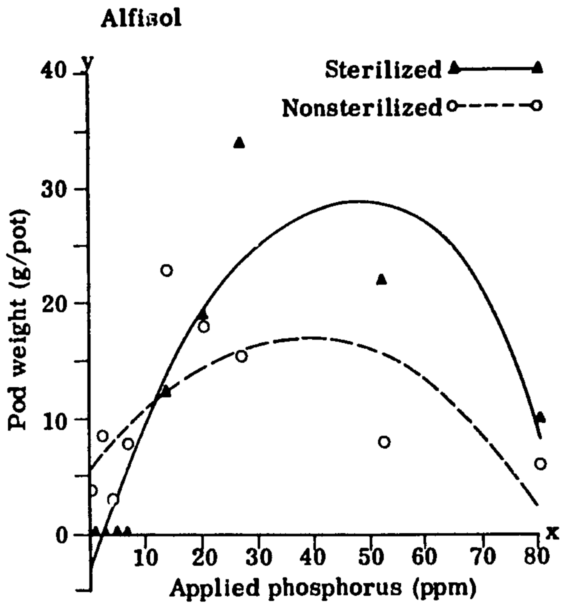
[1] In a band, 5 cm to one side and 5 cm below seed depth.
[2] One-half applied in, and one-half away, from seed row.

Plant heights were measured 3 and 8 weeks after seeding. Diammonium phosphate caused significantly ($P<0.05$) taller plants. Plant height responded markedly to increased N from 40 to 80 kg/ha; the crop without added nitrogen outside the experimental blocks was very poor. However, fertilizer placements caused no significant differences (Table 20), nor were there interactions between placement and fertilizer type or rate of application.

We concluded that any of the three sources of nitrogen we used could be safely placed with sorghum seed in Vertisols at rates upto 80 kg N/ha. But the results should be considered merely indicative until we repeat the investigation on larger plots.

Phosphorus

Several aspects of phosphorus fertilizer strategies are being studied to provide indications for future research. Our timely long-term experiment has clearly indicated that water-soluble P was used efficiently by improved cropping systems on an Alfisol; also that additions of



$y = 6.14 + 0.60x - 0.008x^2$
$R = 0.66$ $rse = 6.11$
$y = -3.40 + 1.50x - 0.016x^2$
$R = 0.91$ $rse = 5.8$

Figure 13. Effect of sterilizing an Alfisol on the response of pigeonpea to added phosphorus in a pot experiment, ICRISAT Center, 1983.

fertilizer-P were much less essential for pigeonpea than for millet or sorghum.

Subsequent studies were aimed at investigating the reason for pigeonpea's ability to yield well with little applied-P on soils very low in P. In pot experiments, using an Alfisol of very low P status, we found good indications that sterilization reduced P uptake so that with less than 10 ppm of added P, plants did not set seed (Fig. 13). From that, we speculate that mycorrhizal associations with pigeonpea roots are responsible for pigeonpea's ability to efficiently absorb phosphorus from soil low in available P.

Preliminary results, reported last year (ICRISAT Annual Report 1982, pp. 253-255), also indicated marked differences between Vertisols and Alfisols in soil-test/crop-response relationships for predicting sorghum's P requirements from an Olsen soil test (which uses 0.5 *M* NaHCO$_3$). Further field experiments, conducted at 4 sites with a range of available soil P, confirmed that responses were substantial only when the Olsen P test value was less than about 2.5 ppm, substantially lower than the approximately 5 ppm considered necessary in India.

More specific comparisons of Vertisols and Alfisols were attempted in a pot experiment with 4 bulk samples collected from each of our benchmark Vertisols and Alfisols at ICRISAT Center. The bulk samples were chosen to provide a range in Olsen P levels for each soil. Relationships between crop response to applied P and Olsen P values did not differ markedly for the 2 soils; however, relationships differed markedly for other assessments of available soil P, e.g. Electro-ultra filtration (EUF) and water-soluble P. We suspect that these results may reflect the confined volume of soil in the pots; further field experiments are indicated.

Maintenance of Soil Fertility

Evaluations from annual experiments of various improved cropping systems have provided much useful information on yield advantages of the systems. However, sustainability of the improved productivity over several years is not known. Two considerations are particularly important: first, improved productivity removes more nutrients (N, P, and K) from the soil, so nutrient supplies may be depleted unless fertilizer applications are increased; second, contributions of the legume in the cropping systems to soil nitrogen status is not known. Several experiments have been initiated at ICRISAT Center to provide such information.

Potassium. Our long-term potassium experiment was established in 1979 primarily to provide information on depletion of K in Alfisols under improved cropping systems. Of particular importance is this experiment's design, involving a rotation of two intercrops, which was intended to minimize buildup of pests and diseases that often accompany continuous monocropping. The cropping system is a simple 2-year rotation consisting of a sorghum/pigeonpea intercrop

(2:1 row arrangement) alternating with a millet/groundnut intercrop (1:3). The three replicates contain duplicate main plots of each cropping system, to allow measurements of the systems each year; nutrient-management treatments were applied to split plots within the main plots. The nutrient-management treatments were designed primarily to assess: (1) the onset of potassium deficiency, (2) the role of various amendments in promoting, or alleviating, exploitive removal of K. Examples of amendments are N fertilizer to promote cereal growth and, thus, K uptake; and, returning residues or adding farmyard manure (FYM) to provide K inputs that could come from a farmer's own resources.

During the first 4-year cycle of the experiment, only modest responses to K were observed. The most consistent effects were in sorghum (Fig. 14); statistically significant responses ($P<0.05$) to added K were obtained in grain yields during the 3rd and 4th years, and in straw yields in all years.

The only substantial increase in sorghum grain yields was in 1981, a particularly wet year. Additions of organic materials (cereal stalks and FYM) with added N (120 kg/ha), gave responses similar to those from equivalent amounts of K added as inorganic K.

Implications of the various treatments on soil K status are indicated in Table 21. Substantial K was removed from the soil over the 4 years (55 kg K/ha per year with no nitrogen added). Most of the K taken up by plants came from reserves in the soil when fertilizer-K was not added; the change in exchangeable-K, i.e. readily available K in the soil, was small. The K reserves are very large, approximately 80000 kg K/ha in the 0 and

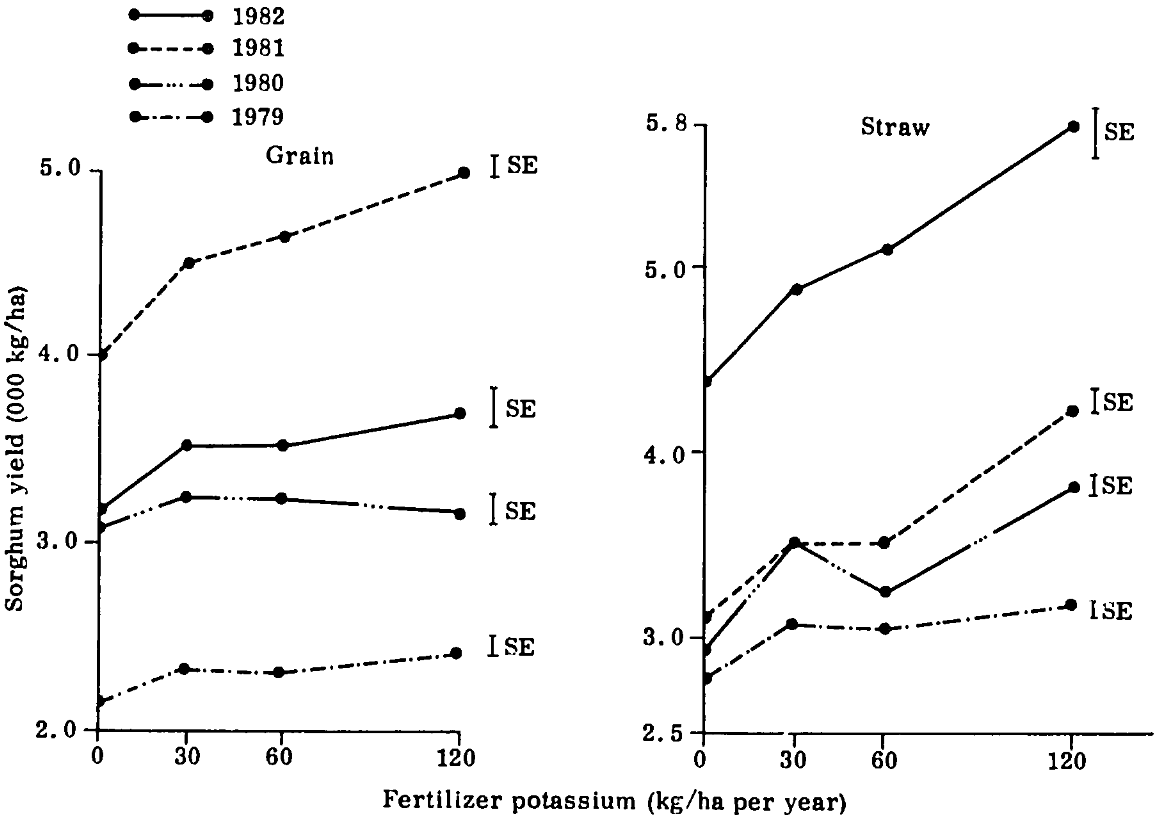


Figure 14. Response of CSH 6 sorghum straw and grain yield to application of fertilizer-K in the long-term potassium experiment; Alfisol, ICRISAT Center, 1979-82.

Table 21. Inputs to and removal of potassium from an Alfisol in the long-term potassium experiment, ICRISAT Center 1979-1982.

	Treatments[1]									
	Control	N_{60}	N_{120}	K_{30}	K_{60}	K_{120}	RR[2]	FYM[3]-N_{120}	FYM	SE
Amendments added/yea.										
N (kg/ha)	0	60	120	120	120	120	120	120	0	
K (kg/ha)	0	0	0	30	60	120	0	0	0	
Organic materials (t/ha)	0	0	0	0	0	0	2.7	5	5	
Inputs of K to soil (kg/ha), 1979-83										
Removal in herbage	-221	-234	-252	-302	-327	-355	-299	-320	-303	±10.5
Added in amendments	0	0	0	120	240	480	191	400	400	
Calculated net input to soil	-221	-234	-252	-182	-87	+125	-108	+80	+97	
Exchangeable-K in soil (ppm)										
1979	65	53	54	60	62	61	58	59	56	±5.8
1983	49	49	48	57	72	84	56	52	56	±4.0
Change over 4 years	-17	-4	-6	-3	+10	+24	-2	-7	0	
Sources of K removal in herbage (kg/ha), 1979-83										
Exchangeable K[4]	-71	-17	-25	-13	+42	+101	-8	-29	0	
Non-exchangeable K	-150	-217	-227	-169	-129	+24	-100	+109	+97	

1. Basal application of 15 kg P/ha to all treatments.
2. Return of residues (cereal straw).
3. FYM = Farmyard manure.
4. Calculated from exchangeable-K concentration by assuming soil apparent density = 1.40 g/cc.

30 cm depth. Clearly, the soil releases K from the reserves at a fairly rapid rate at present, but, we do not yet know how the replenishment rate of exchangeable K will change as reserve K is depleted, or when inputs of K will be required by adding FYM or K. The plant response data suggest that inputs may soon be needed, despite the large K reserves in the soil.

Nitrogen. The use of legumes holds promise for SAT farmers because biological N fixation provides an alternative source of N to fertilizers and, thus, could markedly reduce cash outlays required for the introduction of improved cereal cultivars. Legume N inputs may be preferred where use of fertilizer N is not associated with appreciable risks; for example, on soils where moisture deficiency will be a limiting factor (see Nitrogen Fertilizer Strategies). However, data on the residual effects of legumes are scarce; measurements of N inputs by biological N fixation are rare for the rainfed SAT. Research in this field requires medium- to long-term experiments. Results from two such experiments have now produced promising results.

Long-term potassium experiment. In this experiment, described above, crop yields in the control plot (without additional N or K) increased during the first 4-year cycle (Table 22). Particularly important are the moderately high, stable yields of the sorghum component of an intercrop; the other component (pigeonpea) also yielded well. For comparison, on another Alfisol, sorghum yield after a previous cereal crop was 1100 kg/ha (see Table 23). We attribute the development of sustained high yields of sorghum to the residual nitrogen inputs by legumes, especially groundnut grown in the preceding year; this supplied most of sorghum's

Table 22. Grain yields (kg/ha) of alternating sorghum/pigeonpea and millet/groundnut intercrops in control plot of long-term potassium experiment[1]; Alfisol, ICRISAT Center 1979-1982.

Crops[2]	1979	SE	1980	SE	1981	SE	1982	SE
Sorghum/pigeonpea[3] intercrop								
Sorghum	1900	±61	2780	±173	2770	±196	3180	±154
Pigeonpea	420	±31	320	±51	900	±91	860	±84
Millet/groundnut[4] intercrop								
Millet	600	±32	810	±89	840	±99	830	±74
Groundnut	1320	±78	960	±36	850	±93	1190	±63

1. Basal dressing of 15 kg P/ha per year only to each intercrop; no added nitrogen or potassium.
2. The two intercrops were alternated annually.
3. Two rows of sorghum intercropped with one row of pigeonpea.
4. One row of millet intercropped with three rows of groundnut.

nitrogen requirements, because added fertilizer nitrogen caused a response only in the wettest of the first 4 years (Fig. 15).

Measurements of soil nitrogen content indicated that no significant change occurred during the 4-year cycle (Table 24). On the values obtained, we assess the input by biological N-fixation at about 50 to 100 kg N/ha. This is only a preliminary estimate at this stage in the experiment, as more time is required to reduce the effect of the error in the soil N measurements on the annual rate of N input. However, this indicated level of N fixation is quite encouraging because the legumes were intercrops and covered only a portion of the land. Previous studies by groundnut microbiologists have indicated that N fixation is lower in intercrops than in sole crops.

These results represent a further development in the systematic selection of cropping systems for various edaphic situations. Small-plot experiments, and subsequent operational-scale testing have indicated the most promising cropping systems. The sorghum/pigeonpea intercrop is particularly productive and efficient with LERs

Table 23. Effect of previous crop on grain yield (kg/ha) of rainy-season sorghum CSH 6, and responses to nitrogen; Alfisol, ICRISAT Center, rainy season 1982.

Crop		Rate of applied N (kg/ha)		
Previous (1981)	Current (1982)	0	30	60
Sorghum	Sorghum	1110	2320	2870
Sor/PP[1]	Sor/PP	1420	2300	2420
Pigeonpea	Sorghum	2720	2790	3390
SE			±231	

1. Sorghum/pigeonpea intercrop.

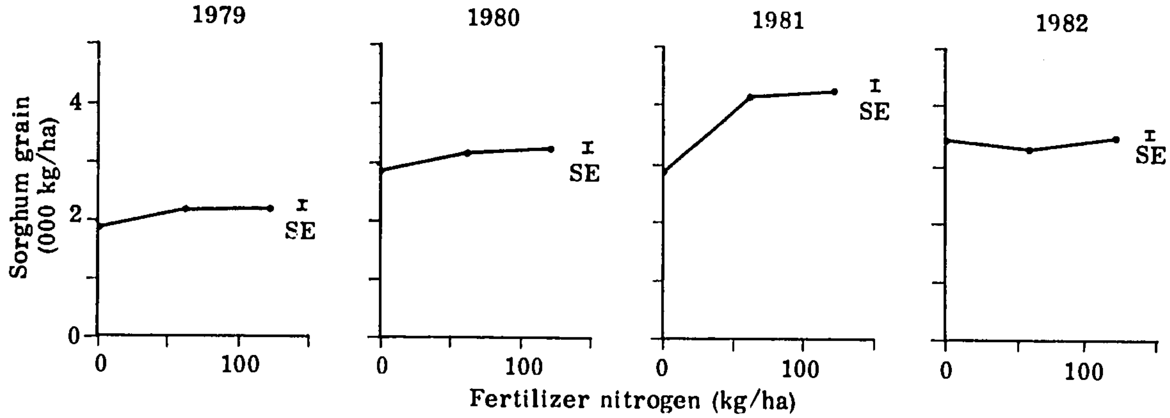


Figure 15. Response of intercropped sorghum to fertilizer-nitrogen on Alfisol, grown after a previous millet/ groundnut intercrop, ICRISAT Center, rainy seasons, 1979-83.

Table 24. Inputs to and removal of nitrogen from an Alfisol in the long-term potassium experiment, ICRISAT Center 1979-1982.

	Treatments									
	Control	N_{60}	N_{120}	K_{30}	K_{60}	K_{120}	RR[1]	FYM[2]+N	FYM-N	SE
Amendments added										
N (kg/ha)	0	60	120	120	120	120	120	120	0	
K (kg/ha)	0	0	0	30	60	120	0	0	0	
Organic matter (t/ha)	0	0	0	0	0	0	2.7	5	5	
Total soil N (ppm)										
1979	458	495	483	500	487	513	545	505	477	±6.8
1983	474	493	498	489	522	531	548	524	517	±15.1
Inputs and outputs, 1979-1983										
Change in soil N										
- ppm	+16	-2	+15	-11	+35	+18	+3	+19	+40	±18.9
- kg/ha[3]	+67	-8	+63	-46	+147	+76	+13	+80	+168	±19.0
Additions as										
Added N (kg/ha)	0	150	300	300	300	300	300	300	0	-
Organic N (kg/ha)	-	-	-	-	-	-	62	314	31	±4
Removals of crop N (kg N/ha)										
Estimated N fixation (kg N/ha)[4]	406	214	163	82	278	215	63	-66	252	
Estimated average N fixation (N kg/ha/yr)	101	54	41	20	70	54	16	-16	63	

1. Return of residues (cereal straw).
2. FYM = farmyard manure.
3. Bulk density assumed at 1.40 g/cc.
4. Estimate of fixation ignores N inputs in rainfall, and losses by leaching and gases.

commonly 1.40 or higher, or a 40% increase in efficiency. Millet/groundnut has given lower LERs, commonly 1.10 to 1.25, but it is a highly relevant intercrop for light-textured soils. In combining these two systems, we can see a possibly unrecognized benefit from intercrops—residual effects on cereal yields in subsequent years.

Also reassuring is the fact that the experiment has not encountered serious pest or disease problems, even after 4 years. The only inputs for the above control treatment were phosphatic fertilizer (15 kg P/ha per annum), and plant protection measures, especially for shoot fly on sorghum and *Heliothis* on pigeonpea. This simple rotation of two intercrops provides a system under which diseases and pests have not developed to any extent, and one that so far seems to maintain the nitrogen component of fertility.

Sole pigeonpea vs intercrops. Assessments of pigeonpea residual effects were obtained in a simple experiment designed to compare residual effects of intercropped vs sole pigeonpea on yield of a subsequent sorghum crop. Treatments involved sole sorghum, sole pigeonpea, sorghum/pigeonpea intercropped, and alternating sole sorghum and sole pigeonpea in a 2-year rotation. On an Alfisol with low soil nitrogen (0.036% N), this experiment promised sensitivity to measure residual effects. Because the site was located in our pesticide-free area (no plant protection measures), the results could have direct relevance to small SAT farmers.

Results from the 2nd year of the experiment (1982) showed excellent residual effects (Table 23); sorghum grain yields without added fertilizer-N were increased from 1110 kg/ha to 2720 kg/ha by growing sole pigeonpea the previous year, compared with growing sorghum in successive years. When pigeonpea was in an intercrop the previous year, its residual effect was not significantly different ($P>0.10$) from that of sorghum. The residual effect of sole pigeonpea was equivalent to an application of 30 to 40 kg N/ha.

The good residual effect of pigeonpea noted in the second year was in addition to approximately 1000 kg/ha pigeonpea grain yield the previous year, when sorghum was almost a complete failure after severe shoot fly attack (200-400 kg/ha). The 3rd year, sorghum and pigeonpea growth over a large area of the experiment was severely depressed by nematode attack. The Pulse Pathology subprogram has identified the nematode as *Hoplolaimus seinhorstii* and this is its first reported infestation of a pigeonpea crop in India.

The above results are encouraging, and agree with earlier results (obtained by the Pulse Microbiology subprogram) showing good residual effects of sole pigeonpea on a Vertisol. They also indicate clearly the need for at least some of the design approaches used in the long-term potassium experiment, such as rotations of different crops to minimize pest and disease build up and the need for plant protection measures to control known pests.

Organic Matter Decomposition

Because of indicated future emphasis on nonfertilizer inputs of nitrogen (biological nitrogen fixation and such recycled nutrient sources as FYM) information will be needed on rates of decomposition for various organic sources of N. Substantial support for such work has been provided by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ); a growth chamber for producing plant material labeled with both ^{14}C and ^{15}N is now being installed.

On-Station Operational Research

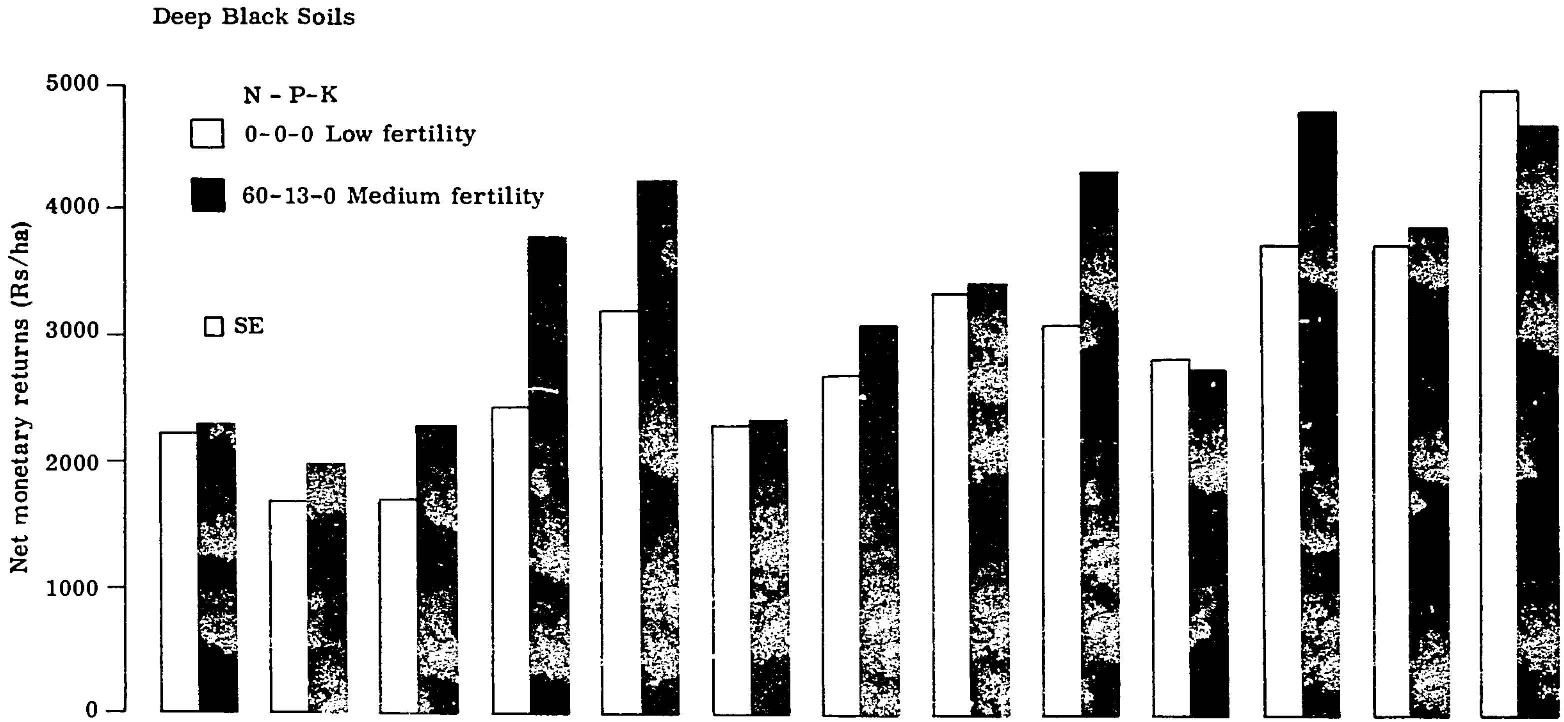
Cropping Systems for Different Soil Types

Operational-scale experiments initiated in 1982 to evaluate cropping system options for different soils were continued in the research watersheds using large plots (200-400 m^2) and three replications. The wheeled tool carrier and broadbed-and-furrow system were used to assess operational feasibility, and costs were calculated to assess economic viability. Two fertilizer levels were included as main plots in a split-plot layout. On the black soils we compared no added fertilizer with 60 kg N plus 13 kg P/ha; for the Alfisol, fertilizers were 20 kg N plus 8 kg P/ha, and 80 kg N plus 17 kg P/ha. Nitrogen was not applied to the legumes. The systems being examined changed little from 1982. Yields and net returns are given in Figures 16 to 19.

Deep Black Soils

Soybean was included this year in a sequential system (soybean-sorghum) and an intercropping system (soybean/pigeonpea) because of soybean's potential importance on wetter deep black soils (particularly in Madhya Pradesh). A smother crop system also was included, with mungbean sown between rows of a sorghum/pigeonpea intercrop; weed-science studies have shown that this seems an effective way to reduce weeding costs.

Sorghum yields again exceeded maize yields, especially at low fertility (Fig. 16); averaged over all systems, sorghum gave 2240 kg/ha compared with 1553 kg/ha for maize at low fertility and 3359 kg/ha compared with 2878 kg/ha at medium compared to low fertility. The higher cereal yields at medium fertility in cereal/pigeonpea intercropping did not reduce pigeonpea yield as they did in 1982. Soybean yields were much higher than either mungbean or cowpea so soybeans clearly have considerable potential as a high yielding, rainy season alternative to the



Yield kg/ha	MB–	MB–	Mai–	Mai–	Mai–	Sor–	Sor–	SB–	Sor/	Sor/	Mai/	Cop/	SB/
Low	708	589	1618	1466	1576	2293	2186	1326	1736	1690	1355	439	1003
Medium	804	633	2869	2949	2815	3229	3488	1343	3063	2447	2617	363	984
	Seq	Seq	Relay	Seq	Seq	Seq	Seq	Seq	IC	IC	IC	IC	IC
	Sor	Chi	Chi	SF	Chp	SF	Chp	Sor	PP	PP/MB	PP	PP	PP
Low	1368	330	240	648	1039	489	828	912	624	426/249	763	954	873
Medium	1982	540	316	898	1221	629	898	1720	781	415/210	773	1140	917

(Seq = sequential; IC = intercrop; Chi = chillies; PP = pigeonpea; SF = safflower; Chp = chickpea; SB = soybean; MB = mungbean; Sor = sorghum; Mai = maize; Cop = cowpea).

Figure 16. Net monetary returns and grain yields from indicated cropping systems grown on deep black soils under low and medium fertility on an operational scale, ICRISAT Center, rainy and postrainy seasons 1982.

cereal crops. In general the legumes showed little response to increased fertility.

Net returns differed less between fertility rates this year than last year. At low fertility, at which 9 of the 13 systems still gave more than 2500 Rs/ha net, all pigeonpea intercropping systems were good; soybean, maize, or cowpea intercropped with pigeonpea gave higher returns than all other systems tried. Of the sequential systems, soybean-sorghum and maize-chickpea gave highest returns. At medium fertility, 8 of the 13 systems gave more than 3000 Rs/ha net. Soybean, maize, or sorghum intercropped with pigeonpea gave highest returns, followed by sequential maize-chickpea or maize-safflower. The smother crop system appeared a reasonable option under low fertility but gave no higher returns under medium fertility. Although the smother system saved on both hand weeding and interrow cultivation, it depressed pigeonpea yields while providing little yield itself. The mungbean sequential systems achieved only low net returns, but these systems are often possible options because very early mungbean adds assurance of being able to sow the sequential postrainy-season crops on time. Chillies, relay-planted amongst maize in September, gave disappointing yields, and consequently this system gave poor returns.

Medium Black Soils

Compared with the deep black soils, the lower moisture-holding capacity of the medium black soils provides less assurance for sequential cropping. The three sequential systems of 1982 were continued; they were based on a first crop of mungbean or early sorghum (CSH 6, which is about 10 days earlier than the CSH 5 used on the deep black soils). The two intercrop systems of sorghum/pigeonpea and mungbean/cotton were also continued. Last year's poorly-performing sorghum ratoon system was replaced by a maize/pigeonpea intercrop.

Yields of sorghum were especially good and, as in 1982, were better than on the deep black soils (Fig. 17). Maize yields were poor, especially at low fertility, but were compensated by better yields of the intercropped pigeonpea. At low fertility the two cereal/pigeonpea systems gave the highest net returns; they were also the most profitable at medium fertility, but the cotton/mungbean intercrop and the sequential systems of sorghum with chickpea or safflower were other good options, all giving more than net returns of more than 4000 Rs/ha at medium fertility. Again, the least profitable of the options tested was the mungbean-sorghum sequential crop; however, this is by far the easiest system from the operational aspect.

Shallow Black Soils

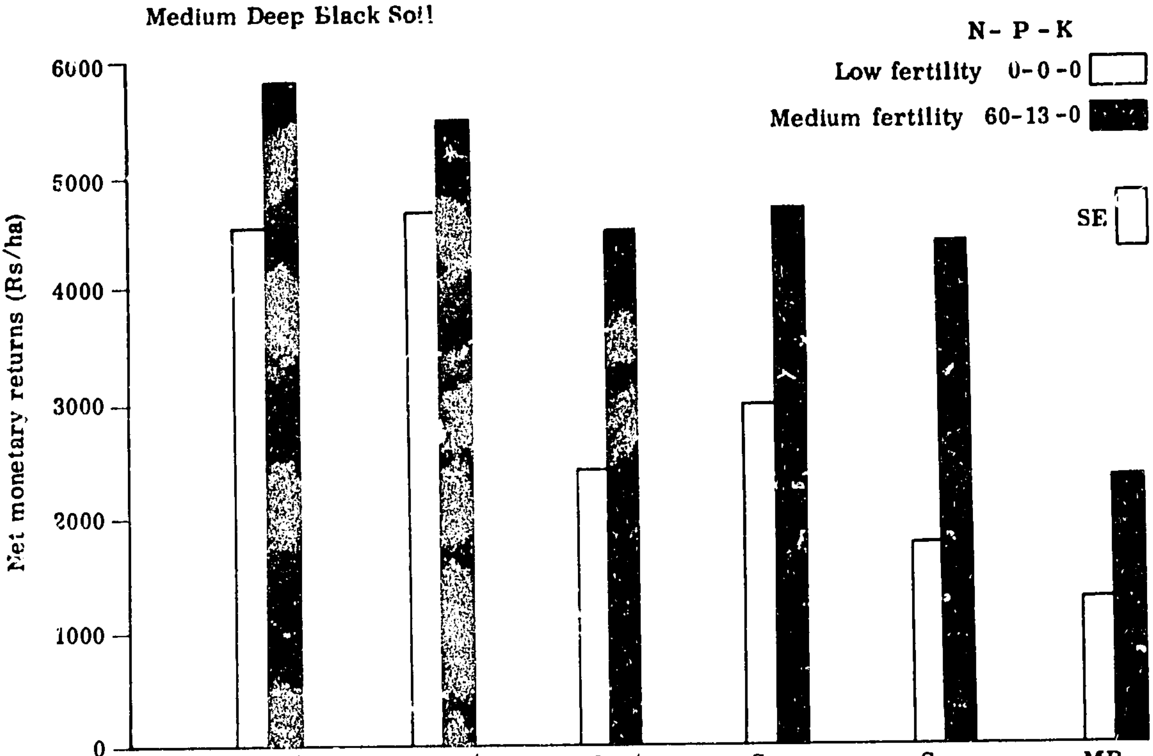
The low moisture-holding capacity of the shallow black soils does not normally allow any opportunity for sequential systems. But cropping intensity can still be increased by intercropping; as in 1982, intercropping systems provided most of the options examined. Sorghum-ratoon and sorghum/millet intercrop system, which performed badly last year, were replaced by castor/mungbean and sorghum/mungbean, but the other systems continued unchanged.

Most yields were better than last year, especially for groundnut and pigeonpea. At low fertility the groundnut/pigonpea gave much the highest net returns (Fig 18), although the two cereal/pigeonpea intercrops, and pigeonpea as a sole crop, also were highly profitable (3000 Rs/ha). Net returns from groundnut/pigeonpea at medium fertility were lower than at low fertility because there was no response to the added fertilizer; these returns were similar to those from the two cereal/pigeonpea systems, and all exceeded 5000 Rs/ha net.

Alfisols

This year 13 systems were examined on the Alfisols. The medium-deep soils used provide some opportunity for sequential crops, if at least one matures very early and particularly if the second one is relay sown. But, as on the shallow black soils, intercropping offers the best opportunity to grow more than a single crop.

Yields varied in 1983, and in general were low



Seed (lint) yield (kg/ha)		Sor/	Mai/	Cot/	Sor–	Sor–	MB–
	Low	2349	483	668	2258	2103	442
	Medium	3611	1879	1168	4307	4120	697
		PP	PP	MB	Chp	SF	Sor
	Low	823	1248	448	856	382	685
	Medium	994	1157	576	1187	1086	1606
		Intercrop	Intercrop	Intercrop	Seq crop	Seq crop	Seq crop

(Sor = sorghum; Mai = maize; Cot = cotton; MB = mungbean; PP = pigeonpea; Chp = chickpea; SF = safflower).

Figure 17. Net monetary returns and seed (pod) yields from indicated cropping systems evaluated for medium deep black soil under low and medium fertility on an operational scale, ICRISAT Center, rainy and postrainy seasons 1982.

(Fig.19). Response to improved fertility also tended to be low and the most profitable systems at medium fertility were, in general, little better than the most profitable ones at low fertility with most returns between only 2000-3000 Rs/ha net. At low fertility, highest returns were from the two cereal/pigeonpea intercrops, followed by millet-cowpea and sole castor. They were also some of the most profitable systems at high fertility, along with groundnut/pigeonpea and mung-bean/castor.

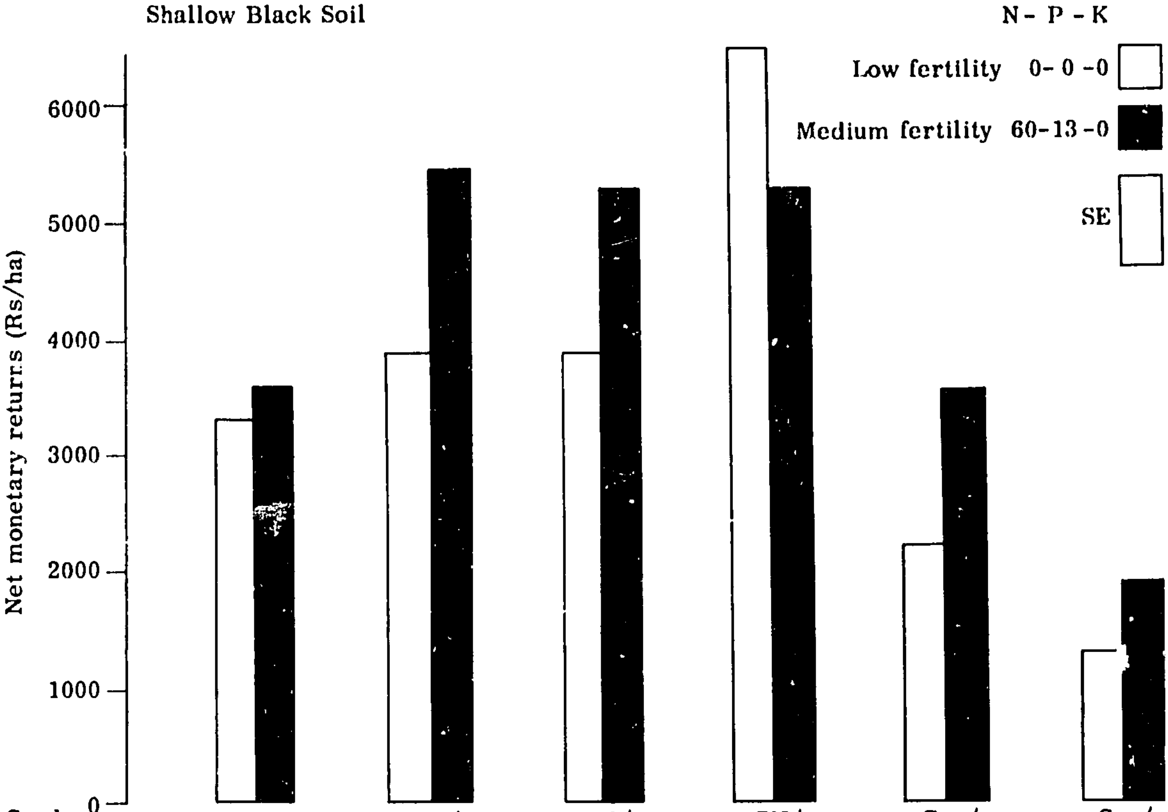
Some millet yields were extremely low, due to occasional malfunctioning of the seeder units. This illustrates the usefulness of the operational nature of these experiments.

Fertilizer and Seed-Planter Unit

Development of a mechanical fertilizer and seed-planter unit, as an attachment to a bullock-drawn WTC, has been a 3-year project. The unit meters seed and fertilizer, and places them at desired positions in the soil, for up to 4 rows of a selected crop in a single pass. The unit has a rectangular hopper divided into two sections for the separate seed- and fertilizer- metering systems. The placement systems were developed during the first 2 years.

During 1983 we combined the metering units, the power transmission system, and the furrow openers. During rigorous testing and evaluations, we modified the clutch, seed-metering plates, and power transmission. The final system is suitable for both the Tropicultor and the Nikart; the only difference between these WTCs is in the mounting frames.

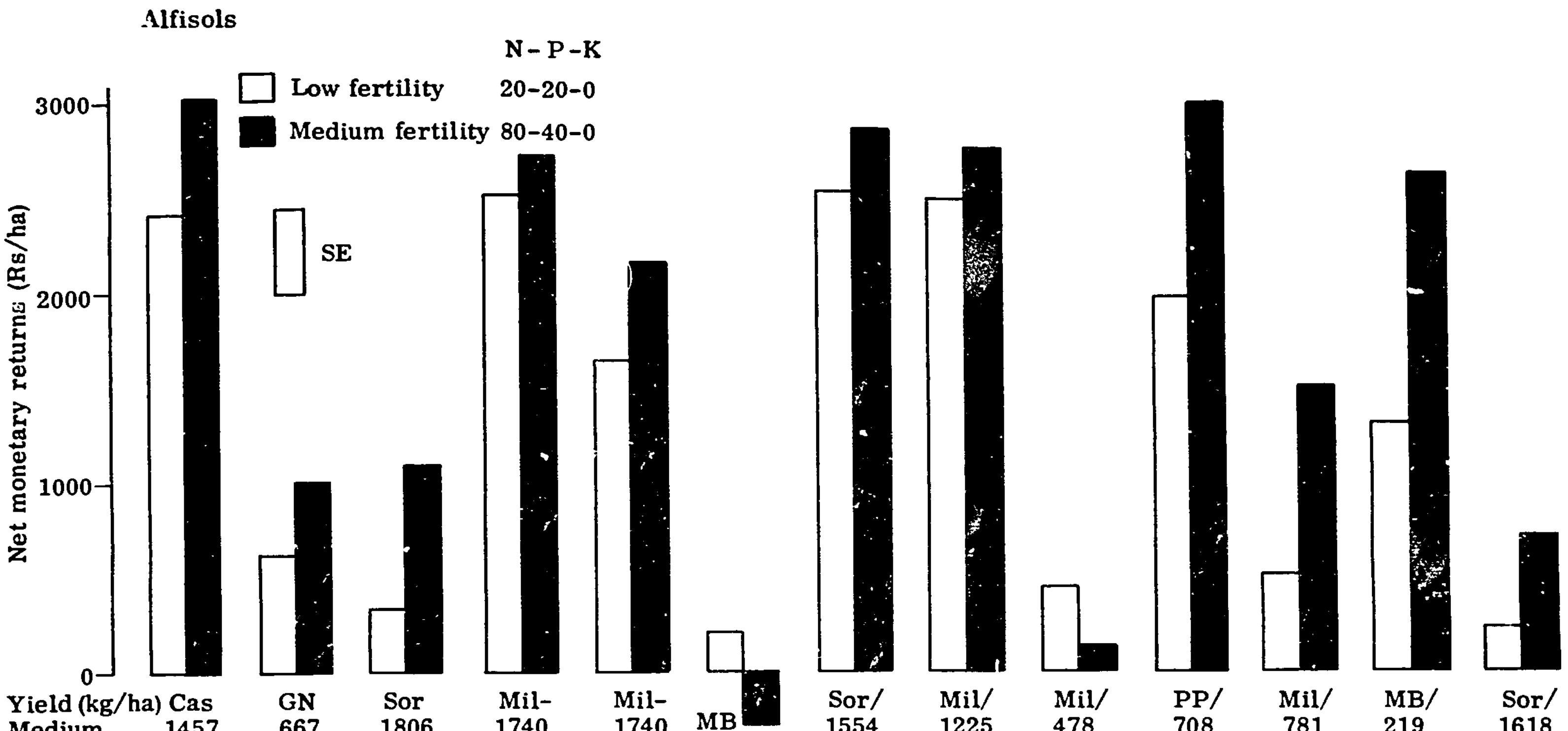
The planter was successfully used for sole crops and intercrops. Good control of the desired seed rate for a particular crop was achieved. It is not necessary to calibrate the drill for a desired seed rate in the field, because the manufacturers' instructions for selecting the



Seed pod yields (kg/ha)		Sole PP	Sor/	Mil/	GN/	Cas/	Sor/
	Low	1041	1312	1397	1153	726	1170
	Medium	1217	3239	2004	2004	1112	2869
			IC	IC	IC	IC	IC
			PP	PP	PP	MB	MB
	Low	-	907	793	1061	380	296
	Medium	-	1052	1174	913	394	198

(IC = intercrop; Sor = sorghum; PP = pigeonpea; Mil = millet; GN = groundnut; Cas = [illegible]; MB = mungbean).

Figure 18. Net monetary returns and seed (pod) yields from indicated cropping systems evaluated for shallow black soil under low and medium fertility on an operational scale, ICRISAT Center, rainy and postrainy seasons 1982.

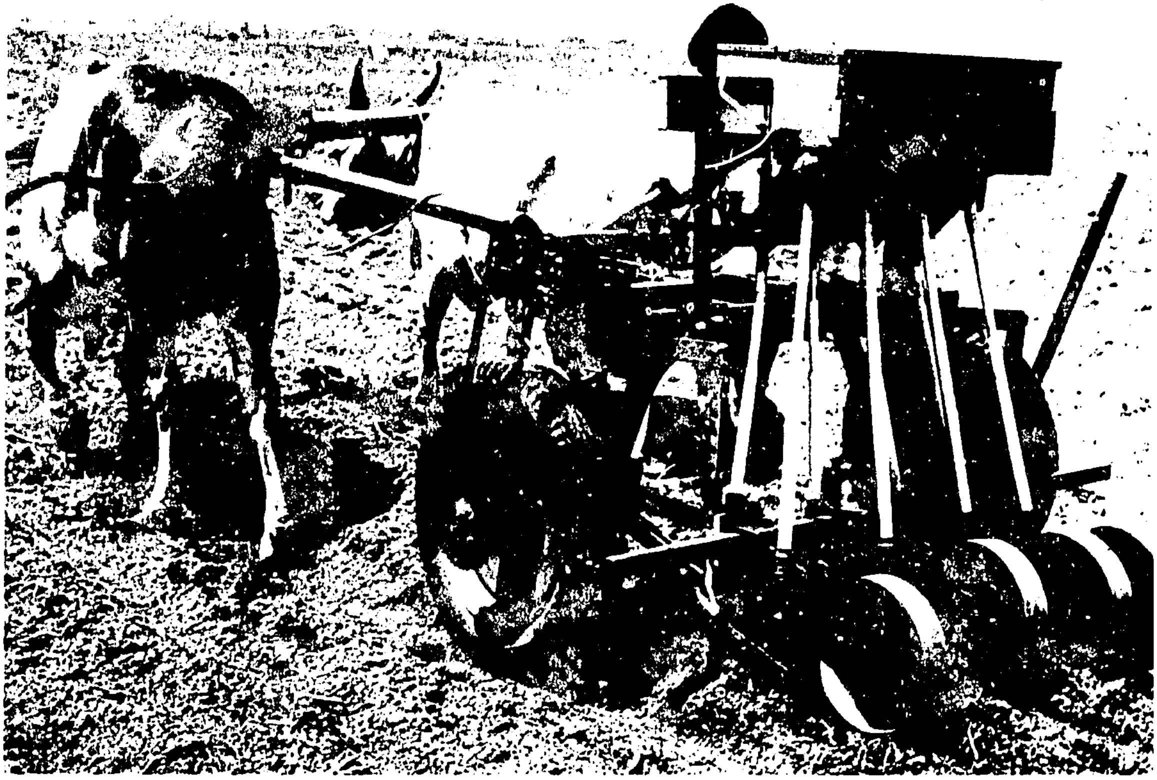


Yield (kg/ha)	Cas	GN	Sor	Mil-	Mil-	MB	Sor/	Mil/	Mil/	PP/	Mil/	MB/	Sor/
Medium	1457	667	1806	1740	1740	235	1554	1225	478	708	781	219	1618
Low	1096	564	767	983	983	206	626	715	256	375	354	203	833

			Ratoon	Seq Cop	Seq HG	Relay Cas	IC PP	IC PP	IC GN	IC GN	IC Cas	IC Cas	IC Cop
Medium			510	806	1012	404	630	649	400	329	767	1197	310
Low			323	657	717	314	681	651	420	521	392	646	177

(Seq = sequential; IC = intercrop; Cop = cowpea; HG = horsegram; GN = groundnut; MB = mungbean; PP = pigeonpea; Sor = sorghum; Mil = millet; Cas = castor).

Figure 19. Net monetary returns and grain yields from indicated cropping systems grown on Alfisols under low and medium fertility on an operational scale, ICRISAT Center, rainy and postrainy seasons 1982.



This planter, developed by ICRISAT, meters both seed and fertilizer and places them at the desired depth in the soil, for up to 4 rows in a single pass. It is readily attachable to the wheeled tool carrier, as shown above.

metering plate were found to be correct. However, application rates for fertilizer varied from the expected for a particular adjustment. We attributed the deviations to variations in manufacturing dimensions from one machine to another, and to changes in the consistency of the fertilizer.

It was easy to plant three rows with the double-shoe furrow opener under most conditions, with an average pair of bullocks. Drafts for 2-, 3-, and 4-shoe operations are given in Table 25. In a well-cultivated soil, 4 rows could be planted at a time but compact soil (Vertisols when sowing a sequential postrainy crop after a rainy season crop) required more power than that provided by an average pair of bullocks. Farmers also complained about the heavy draft under such conditions. We hope to reduce the draft by modifying the furrow openers.

Farmers' reactions to the planter have been generally favorable, because it has given better plant stands than local equipment. On ICRI-

Table 25. Draft of Nikart when operating the fertilizer and seed-planter unit.

Soil type	Crop	No. rows sown	Draft (kg/ha) Range	Mean	SE
Vertisol	Maize	2	90 - 140	108	±11.9
Vertisol	Sorghum/ pigeonpea	3	140 - 170	147	±8.8
Alfisol	Millet	3	100 - 140	124	±16.1
Alfisol	Cowpea	4	130 - 170	153	±12.2

SAT's watersheds the machine covers 1 ha in 4 to 6 hours, depending upon plot size and shape, and other operational factors (Table 26). In comparison, in farmers' fields in the Gulbarga district of Karnataka state, India, hand sowing with traditional equipment required an average 10.2 hr/ha for groundnut or sesame (*Sesamum indicum*) intercropped with pigeonpea. Our mechanical planter required only 4.4 hr/ha for the same crops, a 57% saving in time.

Mechanical Weed Management

Interrow weed management in a rainy season crop can be difficult because of unfavorable soil conditions. Some cultivation implements, such as the blade hoe, appear to control weeds better than duckfoot shovels. But even blade hoes often do not kill all weeds and some reestablish quickly. We therefore evaluated available implements for their ability to control weeds in sole maize on a Vertisol in the rainy season.

We examined 7 systems of interrow weeding. In one treatment preemergence herbicide was applied in addition to mechanical weeding. The other 6 treatments (Fig. 20) involved different weeding tools including a traditional implement used by the local farmers. A weed-free treatment was included as control.

Estimates of the effectiveness of the different treatments were made by collecting surviving weeds, from 1-m^2 sampling areas, 2 days after interrow cultivations. The first interrow cultivation caused significant effects (Fig. 20). The blade hoe plus a preemergence herbicide (T_1), and the blade hoe plus duckfoot shovels (T_3) gave significantly ($P < 0.05$) lower weed populations than the rod weeder (T_5) or farmers' practice treatments (T_4).

The shovels working behind the blade hoe (T_3) were effective because they further damaged weeds cut by the hoe. Cultivation with the blade hoe alone (T_2) was not significantly better than other treatments. As no hand weeding was done after one interrow cultivation for the first six treatments, the pattern of weed growth observed after the second interrow cultivation (26 July) was similar to that after the first cultivation (14 July). But, differences in weed dry matter were not significant after the 2nd cultivation. Although maize yields under different mechanical treatments did not differ significantly ($P > 0.05$) (Fig. 20), there is a trend to an inverse relationship between weed population in July and eventual maize yield.

Evaluation at National Research Centers

The operational evaluation of alternate cropping systems on different soil types at ICRISAT Center is a crucial first step in examining the

Table 26. Field capacity during operation of the fertilizer and seed-planter in different land-management systems.

Soil type	Surface shape	Cropping system	Actual field capacity (ha/hr)
Vertisol	BBF[1]	Maize	0.18
Alfisol(a)	BBF	Sorghum/pigeonpea	0.25
Alfisol(b)	BBF	Millet/pigeonpea	0.21
Alfisol(c)	BBF	Castor/mungbean	0.26
Alfisol(d)	Flat	Sorghum/pigeonpea	0.21
Alfisol(e)	Flat	Millet/pigeonpea	0.20
Alfisol(f)	Flat	Castor/mungbean	0.26
Mean			0.22

1. BBF = boadbed-and-furrow system.

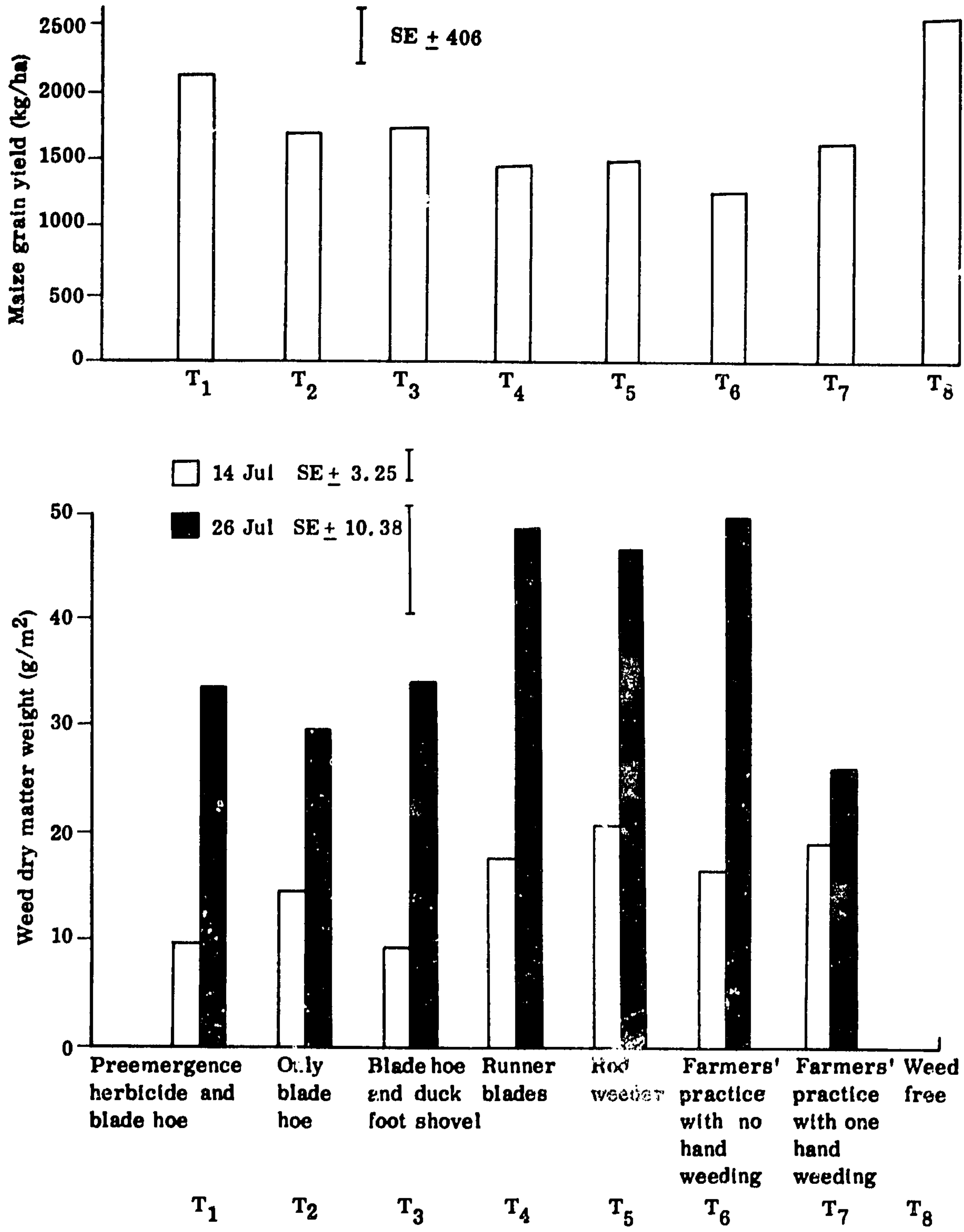


Figure 20. Weed survival two days after first and second interrow cultivation, and grain yield of rainy-season maize on Vertisol, ICRISAT Center, 1982.

feasibility and likely profitability of various options in different environments. In 1982 these studies were extended by commencing similar experiments on national experimental stations situated far from ICRISAT Center. One location was at Begumganj, on a deep black soil in the high rainfall zone (1100 mm) of Madhya Pradesh. The site was on a State Seed Farm immediately adjoining an on-farm watershed and was thus particularly important in screening options for the watershed; it was also useful for demonstrating options to farmers. The other site was located at Talod, Gujarat, on a light-textured Entisol with about 650 mm of rainfall. This experiment was conducted in cooperation with Gujarat Agricultural University on one of their experimental stations. In due course, promising options will be tried on farms in neighboring study villages.

Begumganj

The experiment was conducted in a randomized block design with 4 replications. All crops were grown on a broadbed-and-furrow system and operations were carried out with the WTC. Fertilizer rates were fairly high with a basal dressing of 18 kg N/ha and 20 kg P/ha and a further 62 kg N/ha topdressed on the nonlegumes. Plant protection was carried out at economic levels to control maize stem borer (*Chilo partellus*) and pigeonpea and chickpea pod borer (*Heliothis armigera* Hubner). Sorghum could not be included this year because of the risk of contaminating adjoining seed crops by cross-pollination.

Early rainfall was heavy so timely weed control and nitrogen topdressing were difficult. Maize yields were severely reduced by lack of nitrogen, and soybean yields by weed competi-

A soybean/pigeonpea intercrop included in cropping systems studies at Begumganj, Madhya Pradesh: soybean is becoming an important crop on wetter deep Vertisols. Soybean yielded well despite heavy rains this year, which caused weed and insect problems.

tion; a herbicide treatment on the soybeans gave only partial weed control. Still soybean yields were good, as were those of pigeonpea, chickpea, and safflower.

Of the sequential systems, soybean-chickpea and soybean-safflower gave highest net returns (Fig. 21). The earlier JS 2 soybean yields bettered the locally recommended JS 72-44, and JS 2's early maturity allowed earlier seeding of the sequential postrainy-season crop, and thus a much better wheat yield or a slightly better safflower yield. Maize sequential systems gave lower returns because of poor maize yields; yields of an earlier maize variety were low and the following crop was not improved. Of the intercropping systems, soybean/pigeonpea was good, as were maize/soybean followed by chickpea, then maize/pigeonpea intercrop. Nine of the 13 systems gave net returns above 4500 Rs/ha; such high returns from so many systems was particularly heartening in view of some low first-year yields in the adjoining on-farm watershed.

Talod

This experiment examined 23 systems, comprising either single crops or intercrops in randomized block design with 4 replications. Fertilizers were the same as at Begumganj and all systems were sown by hand. Economically feasible plant protection was used against cereal stem borer and castor semilooper (*Achaea janata*). Total rainfall during the season (630 mm) was around average but the delayed onset of the rains prevented sowing until 15 July; early rainfall was also erratic. As a result yields were generally low, though yields of mungbean, millet, pigeonpea, and castor were satisfactory. Detailed costs could not be estimated so gross returns are given in Figure 22.

Of the 13 intercropping systems examined, 10 gave yield advantages of over 50% compared with their equivalent sole crops; as with the operational-research experiment on an Alfisol at ICRISAT Center, these results emphasize the importance of intercropping systems in increasing cropping intensity on light-textured soils. All the systems that combined an earlier-maturing crop with a later-maturing pigeonpea or castor gave good returns; the best was sesame/pigeonpea or mungbean/castor.

On-Farm Verification Trials

On-Farm Testing of Improved Vertisol Management Technology

In 1981, ICRISAT initiated on-farm verification trials (OFVT) of our Improved Vertisol Management Technology (IVMT) for deep Vertisol areas with assured rainfall (Fig. 23). Key components of ICRISAT's systems were tested in farmers' fields. In these OFVTs, operations were closely monitored and yields were measured to allow subsequent evaluation of the economic viability of the system, and to detect problems and their causes.

The OFVTs had a modest beginning in 1981, involving 14 farmers at Taddanpally, 40 km from ICRISAT Center, with very similar soils and agroclimate.

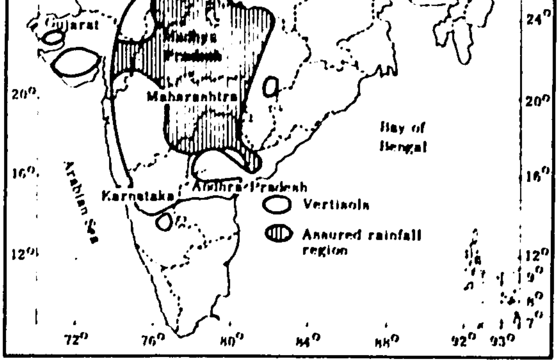
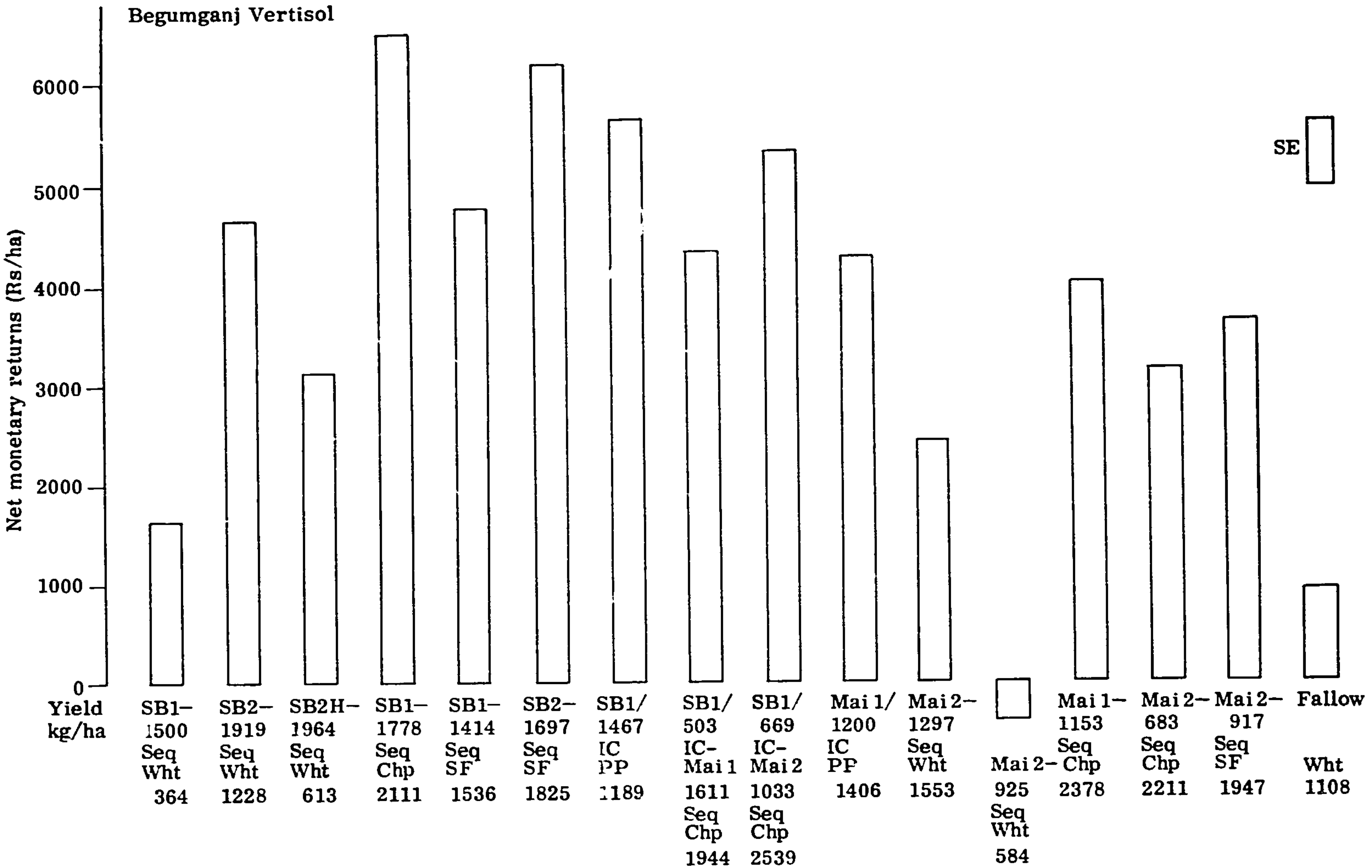


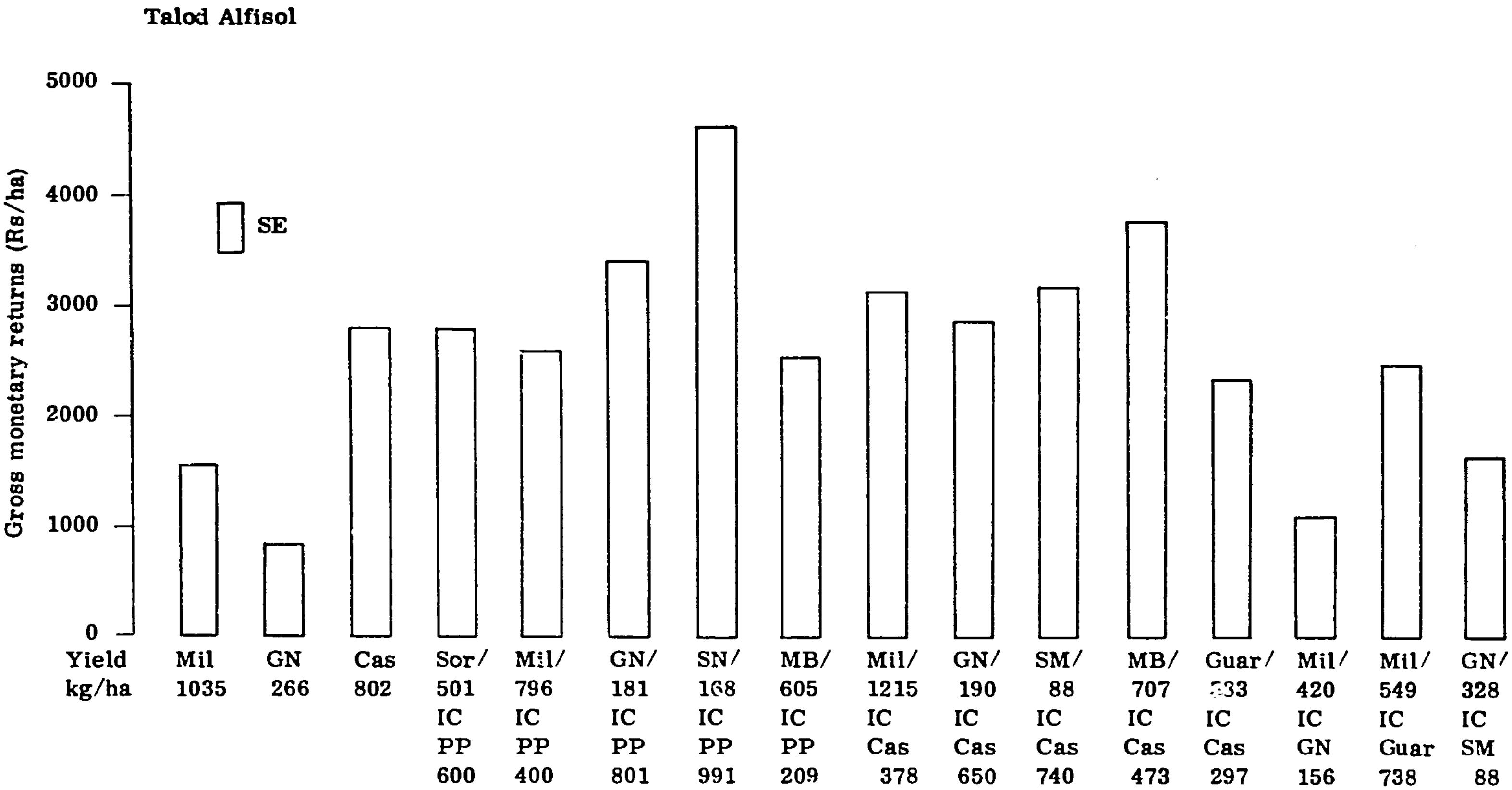
Figure 23. Vertisol areas of India, classified by dependability of rainfall.



(H = herbicide; SB1 = late soybean JS 72-44; SB2 = early soybean JS-2; Seq = sequential; IC = intercrop; Mai 1 = maize D101; Mai 2 = early maize Ganga 5; PP = pigeonpea; Chp = chickpea; SF = safflower; Wht = wheat).

Figure 21. Net monetary returns and grain yields from indicated cropping systems grown on deep Vertisols, Begumganj, rainy and postrainy seasons 1982.

Multilocation testing provides information valuable for adapting ICRISAT's deep Vertisol technology to varying situations. Above, farmers in Anthwar village, Andhra Pradesh, narrate some of their experiences to ICRISAT visitors. Below, an ICRISAT agronomist explains techniques to agricultural officials in Karnataka.



(IC = intercrop; Mil = millet; Cas = castor; Sor = sorghum; GN = groundnut; SM = sesame; MB = mungbean; PP = pigeonpea).

Figure 22. Net monetary returns and grain yields from indicated cropping systems grown on Alfisols, Talod, rainy and postrainy seasons 1982.

The Taddanpally project began with appreciably more input from ICRISAT than has been given at any subsequent site. We provided strong direction and technical support services for the first 2 years. These were then withdrawn to allow observations of adoption by farmers.

To gain experience in areas with problems different from those close to ICRISAT Center, ICRISAT then scientists extended OFVTs in 1982 to Farhatabad, Karnataka, and Begumganj, Madhya Pradesh, where ICRISAT staff supervised day-to-day operations. At other locations, OFVTs were commenced in 1982-1983, by State Departments of Agriculture, with ICRISAT advice being given on request. Observations from these locations suggest that perceptions of the applicability of the technology varied from region to region, and certain components need to be adjusted to suit the soil, crop and agroclimatic characteristics of each region.

In addition to technology verification on farmers' fields, land and water management practices and cropping systems trials were initiated at two government seed farms in Madhya Pradesh and at Talod Experimental Station in Gujarat in collaboration with Gujarat Agricultural University. These trials provide very relevant experimental support for the on-farm research, as an intermediary step is essential in areas which have substantially different soils and agroclimate from those at ICRISAT Center.

Thus, from the initial on-farm testing at a single location, involving 14 farmers on 15.4 ha at Taddanpally in 1981, the OFVTs have expanded to 22 locations covering 1235 ha in 4 Indian States, in 1983 (Fig. 24).

Economic Aspects

The improved watershed-based technology options, tested in the OFVTs in the dependable-rainfall Vertisol region, continued to perform well in 1982-83. The marginal rate of return on additional investment ranged from 26 to 381%, averaging about 240% (Table 27).

The development cost of the 1982-83 on-farm watershed trial sites ranged from Rs. 132 to Rs. 1035/ha (Table 28). The higher cost in Begumgunj reflected higher drainage expenses associated with higher rainfall and the use of tractors instead of bullocks to develop the watershed. Even at about Rs. 1000/ha, the cost of watershed development is preferable to an investment in irrigation.

Earlier results (ICRISAT Annual Report 1978-79, pp. 238-240), based on only one or two dominant cropping systems, indicated that the new technology might greatly accentuate the seasonal demand for labor. But the variety of cropping systems tested left seasonality in labor demand unchanged from traditional practices (Fig. 25).

At Begumganj, the improved technological options showed considerable promise despite their low relative profitability. An unusual dry spell in late June and early July followed by uninterrupted rains led to a poor crop stand and ineffective weed control with no possibility of topdressing fertilizer. Yet, several encouraging signals emerged from the Madhya Pradesh experience. First, all farms in the area suffered from the unusual rainfall pattern and on average

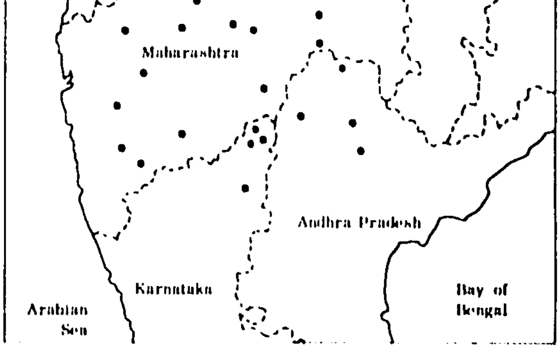


Figure 24. On-farm verification trials of deep Vertisols management technology, 1982/83 (dots indicate locations).

Table 27. Annual profitability (Rs/ha) of improved Vertisol technology options compared to farmers' present practices in On-Farm Verification Trials (OFVT), 1982-83.

Village (district) (state)	Comparative profitability						
	Weighted profits (Rs/ha)			Operational costs (Rs/ha)			Marginal rate of return (%)
	Improved	Traditional	Difference	Improved	Traditional	Difference	
Taddanpally Medak Andhra Pradesh	3957	1722	2235	1035	448	587	381
Sultanpur Medak Andhra Pradesh	3576	1722	1854	1062	448	614	302
Farhatabad Gulbarga Karnataka	3323	2186	1137	1194	1142	52	-[1]
Begumgunj Raisen Madhya Pradesh	1172	786	386	2348	866	1482	26

1. Differences in operational costs too meager for meaningful comparison.

yielded only Rs.800/ha profit. The farmers cooperating with ICRISAT recognized that it was a bad year and 8 of the 10 agreed to continue in 1983-84. Moreover, some cropping systems, such as the soybean/pigeonpea intercrop gave substantial profits (Rs.3535/ha), followed by sequential soybean-lentil's Rs.215/ha. And seed farm experiments showed considerable potential for maize-based cropping systems with 3- to 4-ton/ha yields.

At Farhatabad in Karnataka the average rainfall is only 700-750 mm/year and less dependable than at ICRISAT Center. Several cropping systems gave substantial net returns: sole pigeonpea provided Rs.4186/ha followed by the mungbean-sorghum with Rs.4059/ha. This compared favorably with the existing cropping system which gives a return of Rs.2262/ha. The Karnataka Department of Agriculture envisages a substantial increase in use of this new technology and is proposing considerable expansion in 1983-84.

At Taddanpally, where rainfall is similar to that at ICRISAT (750 mm/year, dependable), the sorghum/pigeonpea intercrop produced best yields and highest returns (Rs.4859/ha). The most important determinant of profitability in the improved cereal/pigeonpea intercrop in

Table 28. Development costs (Rs/ha) of the 1982-83 OFVT watersheds.

OFVT site	Land smoothing	Main and field drains	Forming broadbeds and furrows	Surveying and other expenses	Total
Sultanpur	39	105	28	50	222
Farhatabad	45	13	114	10	132
Begumganj	153	487	320	75	1035

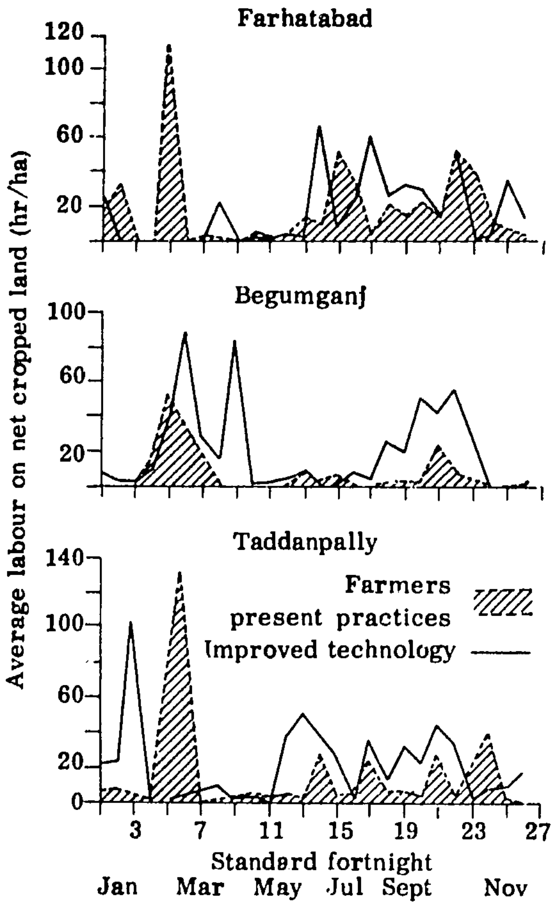


Figure 25. Average seasonal labor use with farmers' present practices and improved Vertisol technology options.

Andhra Pradesh is effective control of *Heliothis armigera*. With efficient spraying techniques, farm profits could have been boosted another Rs.2500/ha.

Although the cereal/pigeonpea intercrop and cereal-pulse sequential crops showed substantial profits the first year, neither was given wider adoption in the 2nd or 3rd years. Farmers tended to revert to their previous systems based on postrainy-season sorghum; there was, however, interest in testing the introduction of a mungbean crop in the preceding rainy season. The reasons for the farmer's choice of cropping systems are being examined.

Lessons Learned from On-Farm Verification Trials

Multilocational testing has provided valuable information for further studies and adapting the technology to different situations. Last year, (ICRISAT Annual Report 1982, pp. 311-312) we discussed several policy issues that required attention before the technology options could be regarded as having real potential. Although some improvements have been made, major problems remain.

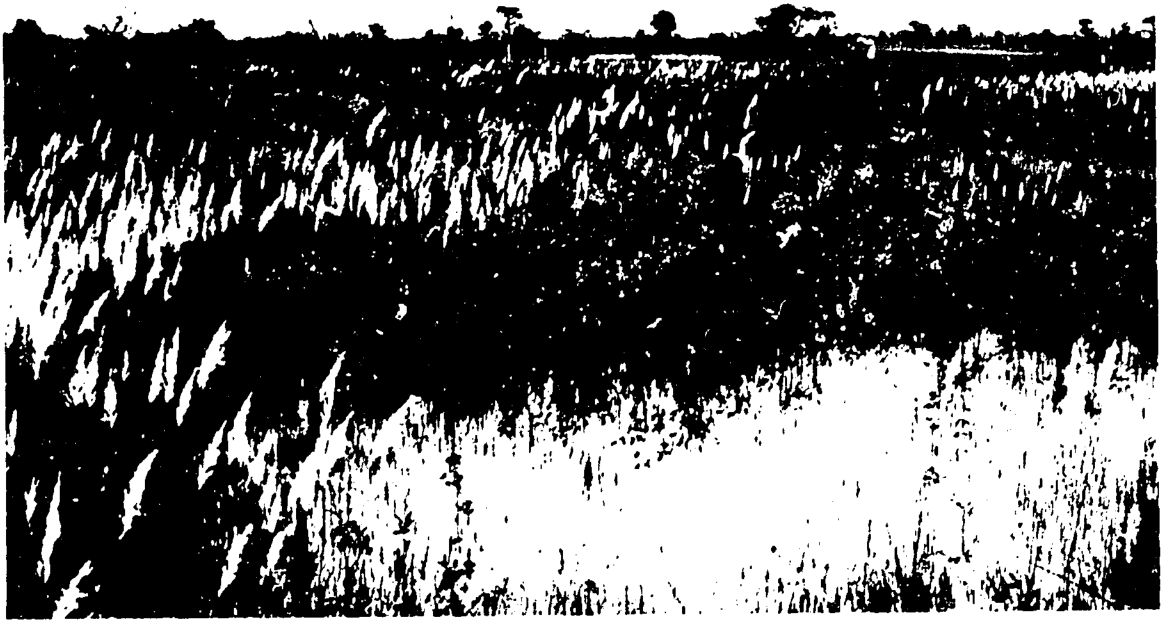
- Intensive training of farmers and agricultural personnel is essential for successful transfer of the technology.
- All components of the IVMT may not be necessary. Multilocational testing has indicated that, in certain cases, components such as dry seeding or shaping the land into broadbeds and furrows may not be essential. Individual cases will determine how best to adjust the technology to be location specific.
- Risk factors. Farmers must have assurance that a basic crop yield can be obtained before they accept new practices. They may prefer a lower but assured yield.
- Weed management during the rainy cropping season is still a problem for many farmers. Interculture with the WTC is only partially successful; more research is required.

Cropping Entomology Studies

Many of the high yields obtained in farmers' fields depended on successful pest control. Last year, poor pest control resulted in substantial crop damage and yield losses (up to 50 to 60%). In particular, pigeonpea was attacked by *Heliothis armigera*. On-farm monitoring of pests, and training farmers in pest control were, therefore, given priority in 1982-83 at Begumganj, Taddanpally, and Farhatabad.

We concentrated our monitoring at Taddanpally as it was much nearer to ICRISAT Center and larger than the other sites.

Our on-farm verification trials in 1983 underlined some problems in implementing ICRISAT's deep Vertisol technology. Above, waterlogging in a field at Anthwar village, Andhra Pradesh, caused by incomplete preparatory work on drainage. Below, weeds abound under very wet conditions at Begumganj, Madhya Pradesh. ICRISAT's training will focus on ways to avoid such problems.



Taddanpally-Sultanpur. On this Vertisol watershed, farmers mainly grew a rainy-season sorghum/pigeonpea intercrop. Deadhearts in sorghum reached 3.6% due to shoot fly (*Atherigona* spp) infestation and 25% due to stem borer (*Chilo partellus*) attack. Infestation by armyworm (*Mythimna separata*) averaged 8 larvae/100 plants during the vegetative stage, and 20 larvae/100 plants during the earhead stage. *Heliothis armigera* infestation averaged 22 larvae/100 earheads. Of the other common insect pests of sorghum, aphid (*Rhopalosiphum maidis*) and head bug (*Calocoris angustatus*) were active.

H. armigera infested all crops except chillies (Fig. 26) but heavily damaged only pigeonpea. On mungbean (*H. armigera*) larvae were 18% parasitized by mermithid (*Ovomermis albicans*).

Farmers were advised to spray their pigeonpea crops, but many did not use the recommended endosulfan or did not apply it at the right time. They used DDT, because it was cheap, and sprayed the crop with a hand-operated or motorized knapsack sprayer. We conducted a simple demonstrations on one of the fields of the watershed with endosulfan applied by hand-operated knapsack, motorized knapsack, and controlled-droplet (CD) sprayers. Our demonstrations were in 3 contiguous blocks, each approximately 0.6 ha (Table 29). We applied endosulfan 35% emulsifiable concentrate (EC) at 2 liters/ha and obtained pigeon-

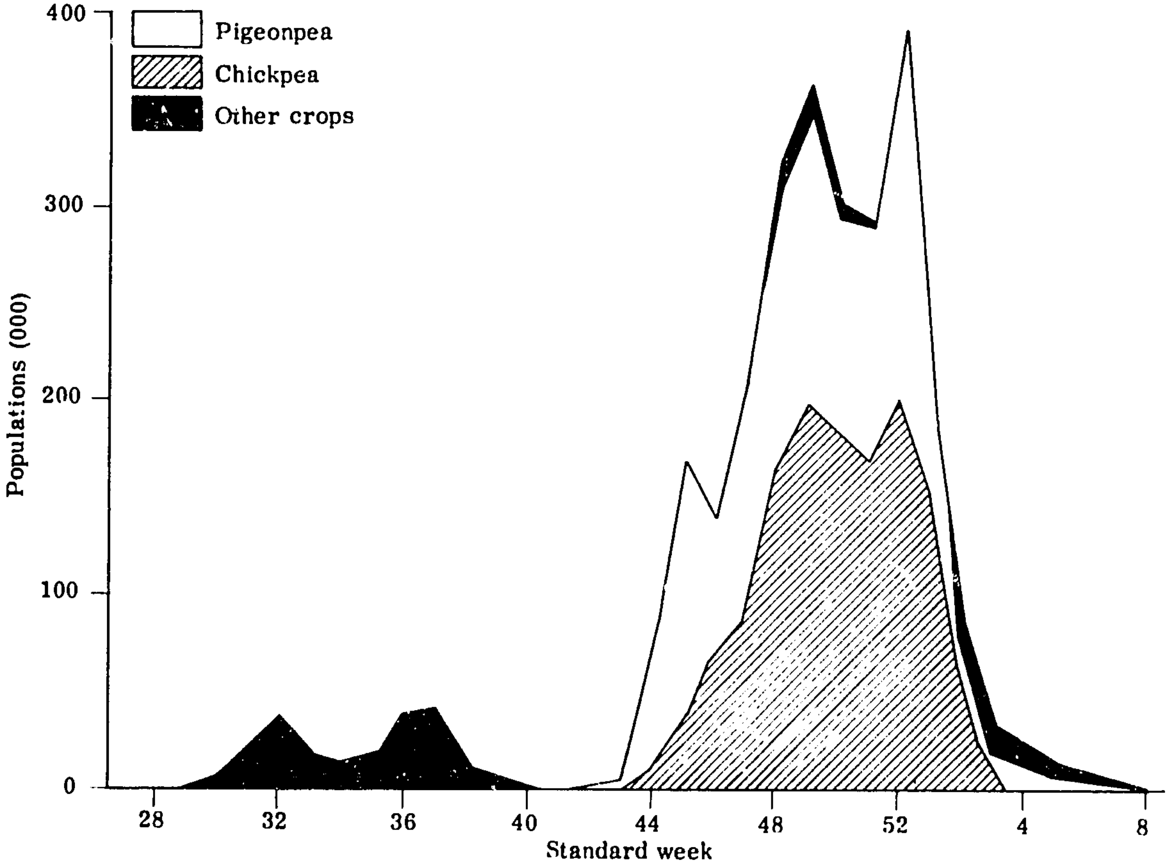


Figure 26. Populations of *Heliothis armigera* larvae on crops in the Taddanpally-Sultanpur Vertisol watershed, 1982-83.

Table 29. Pod damage (%) and cost (Rs/ha) of plant protection in pigeonpea in demonstration trial and in farmers' fields of Taddanpally-Sultanpur Vertisols watershed, 1982-83.

Spray method	Pods (%) damaged by[1]				Total insect damage (%)	Cost of plant protection (Rs/ha)				Yield (kg/ha)
	Bo	Po	Hy	Br		Insecticide	Labor	Others	Total	
Hand-operated[2]	9.5	8.3	4.5	0.0	21.2	320	84	-	404	1170
Motorized[2]	18.9	13.2	5.5	0.0	35.7	320	28	14	362	1250
Controlled Droplet[3]	7.7	11.5	3.4	0.1	21.5	320	14	25	359	1150
Farmers' local[4] (Mean of 9 fields)	71.6	12.7	3.1	0.2	81.7	51	18	9	78	190

1. Bo = borers; Po = podfly, Hy = hymenoptera; Br - Bruchids;
2. Knapsack sprayers used to apply endosulphan;
3. Insecticide used was endosulfan.
4. Insecticide used was usually DDT, occasionally endosulfan

pea yields of more than 1000 kg/ha in all blocks, while the farmers' average yield was only 190 kg/ha despite 2 or 3 applications of insecticide, mainly DDT. This demonstration convinced the farmers of the importance of using the appropriate insecticide, and correct application methods, and especially the need to use the CD sprayer to cover their tall, dense pigeonpeas.

Some farmers sowed sorghum, safflower, or chickpea after the rainy season. Sorghum suffered little insect damage but chickpea and safflower were attacked by *H. armigera*. Farmers did not spray because the insect attack was not severe.

Begumganj. Sorghum or soybean intercropped with pigeonpea were largely grown at this location. Crops in general suffered little from insects, although our light and pheromone traps caught many *H. armigera* and *Spodoptera litura* moths. The soybean girdle beetle *Oberia brevis* swed, which is common in most years in this area, did not appear.

Pigeonpea, which flowered late in January, attracted some *H. armigera*, with an average of 5.3 larvae/10 plants. Most farmers protected their crops by applying one spray of either phosphamidon (Dimecron®) or endosulfan, and obtained a grain yield of 602 to 1447 kg/ha with an average loss of 14.5% to insects. *Eriborus argenteopilus*, a parasite of *H. armigera*, was active in this region.

After sole soybean, farmers sowed chickpea, linseed, wheat, mustard, or lentil. All crops except chickpea were invariably free from pests. Chickpea was dusted or sprayed once for *H. armigera* control.

Farhatabad. At this watershed, we only monitored *H. armigera* on pigeonpea, which is the most important and best protected crop of the region. Farmers obtained yields of 800 to 1350 kg/ha at a cost of Rs.862-1026/ha for plant protection. They applied 6 or 7 dusts/sprays of DDT, endosulfan, quinalphos, malathion, or monocrotophos.

Incorrect insecticide application at one place, and high usage of insecticide at another, highlight the need to train farmers on plant protection and in their own fields, rather than at research centers.

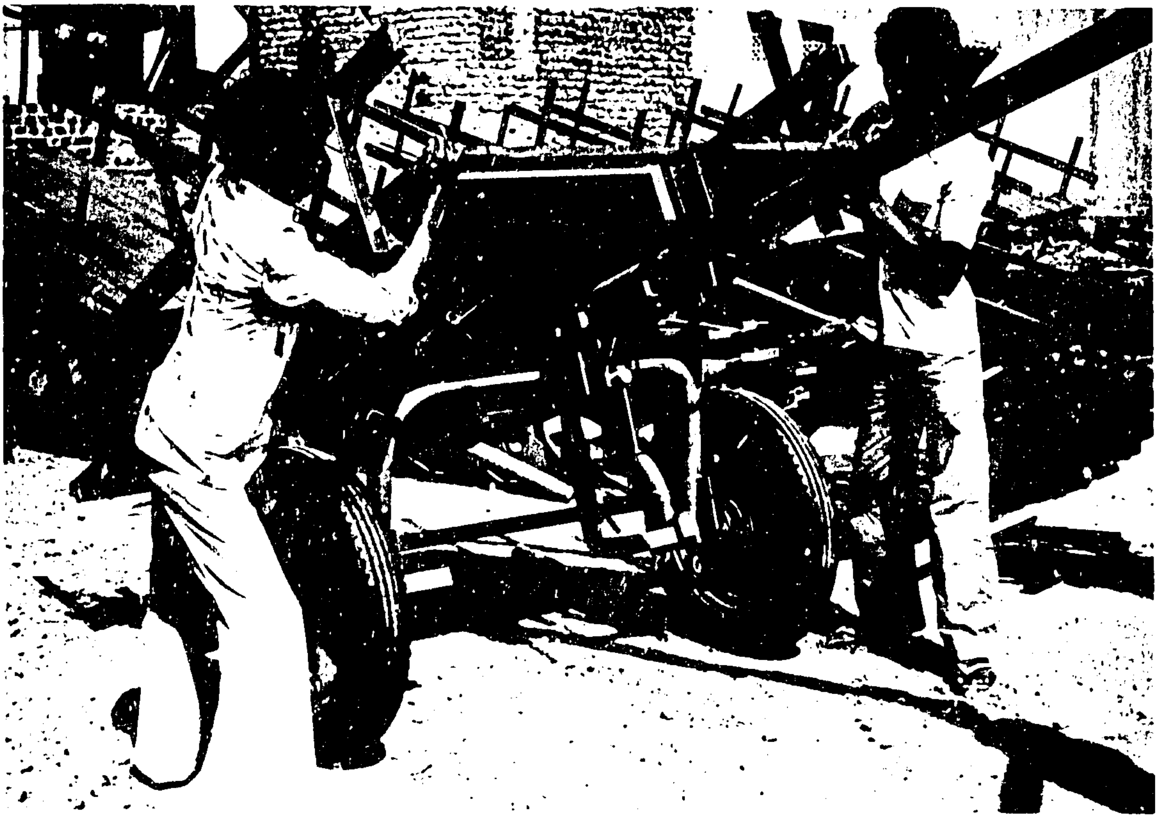
Support to Manufacturers of Improved Equipment

To ensure availability to farmers of improved equipment from local sources, we provide technical support to a few manufacturers. This helps our multilocational OFVTs by promoting the availability of equipment. Another benefit is feedback concerning our improved designs and modifications.

ICRISAT's assistance to manufacturers is usually limited to providing drawings and training. Their technical staff often visit ICRISAT Center to see new or modified equipment in action before making their own prototype. When such a prototype is ready, ICRISAT engineers visit the manufacturer to discuss problems and offer remedial measures. When required, manufacturers' representatives receive training at ICRISAT so they can provide effective demonstrations and after-sales service to farmers.

Such technical cooperation with small industries in India began in 1979, with only a few manufacturers. Several industries showed early interest in the WTC and its implements. But, until 1982, only 2 companies maintained a continuous interest in manufacturing and marketing the WTC. One major reason for the low rate of manufacture could be the slow growth of demand. Sales of fewer than 100 machines of each type per year the first 4 years (1979-1982) illustrate the slow early adoption rate (Fig. 27). Most of the early machines were purchased by research institutions.

Sales of the WTC increased dramatically in early 1983, for several interrelated reasons: promising results of OFVTs: better awareness of improved animal-drawn machinery's usefulness; better acceptance of the WTC by government extension agencies; and price support from the government in some states. The machines are now being used for transport as well as for cultivation; we originally envisaged transport as a secondary use.



The wheeled tool carrier converted into a transport cart at a manufacturer's outlet in Hyderabad, India. ICRISAT's technical support to manufacturers of improved farm equipment enables better access to such equipment for farmers.

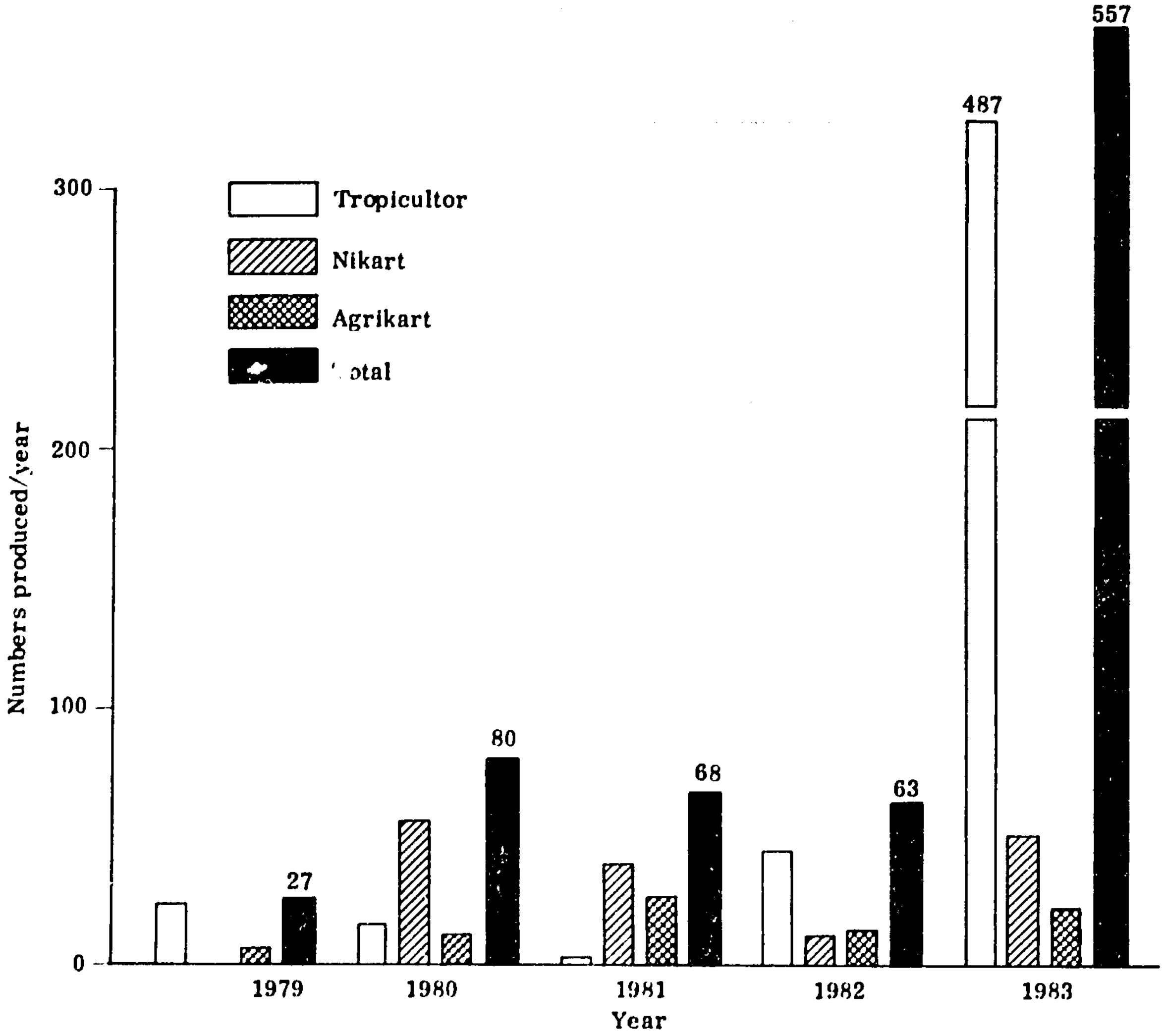


Figure 27. Annual production of wheeled tool carriers in India.

Now there are 4 small manufacturers producing the 3 models of WTC and a full range of implements at different locations in India. Farmers are accepting the improved animal-drawn equipment, particularly where our improved farming systems are showing positive results. The major constraints are high initial cost, and poor quality control in manufacturing. Some of these problems will be reduced by promoting greater awareness of the need for quality control by manufacturers, and healthy competition.

International Cooperation

Resource Evaluation

Agroclimatology

As a part of our efforts to compile an inventory of SAT agricultural resources for agricultural research and extension workers, and planning agencies, we are assembling and analyzing climatic data for several SAT countries, in cooperation with their national meteorological services. During 1983, we assembled climatic data of Upper Volta and Mali, studied distributions, and calculated expected rainfall at different probabilities.

Upper Volta. We collected data for 58 locations representing 522 station years. This report presents sample data for 4 locations (Boromo, Ouagadougou, Yako, and Djibo) where ICRISAT scientists are conducting village level studies and other research (Fig. 28).

Our studies (Tables 30 and 31) show that the length of the rainy season is related to the total rainfall received. Boromo, the wettest of the 4 locations, has the longest rainy season (over 150 days) while Djibo, the driest, has the shortest (about 90 days). The prerainy season, when cultivation and seedbed preparation are done, is fairly long and the dependable rainfall for all locations is quite low (20 to 35 mm). Preliminary analyses show that the potential for double cropping under high management conditions exists at Boromo and Ouagadougou; Boromo, Ouagadougou, and Yako, are equal and < Djibo. This analysis will be useful for interpretations of the cropping systems information gathered by economists in village level studies.

Mali. Long-term daily rainfall records for 81 locations in Mali were supplied by ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer), Paris, in 1977; these were updated to 1980 with the cooperation of the Government of Mali Meteorological Services. From this data, we have computed the annual rainfall isohyets for Mali (Fig. 29). Further data

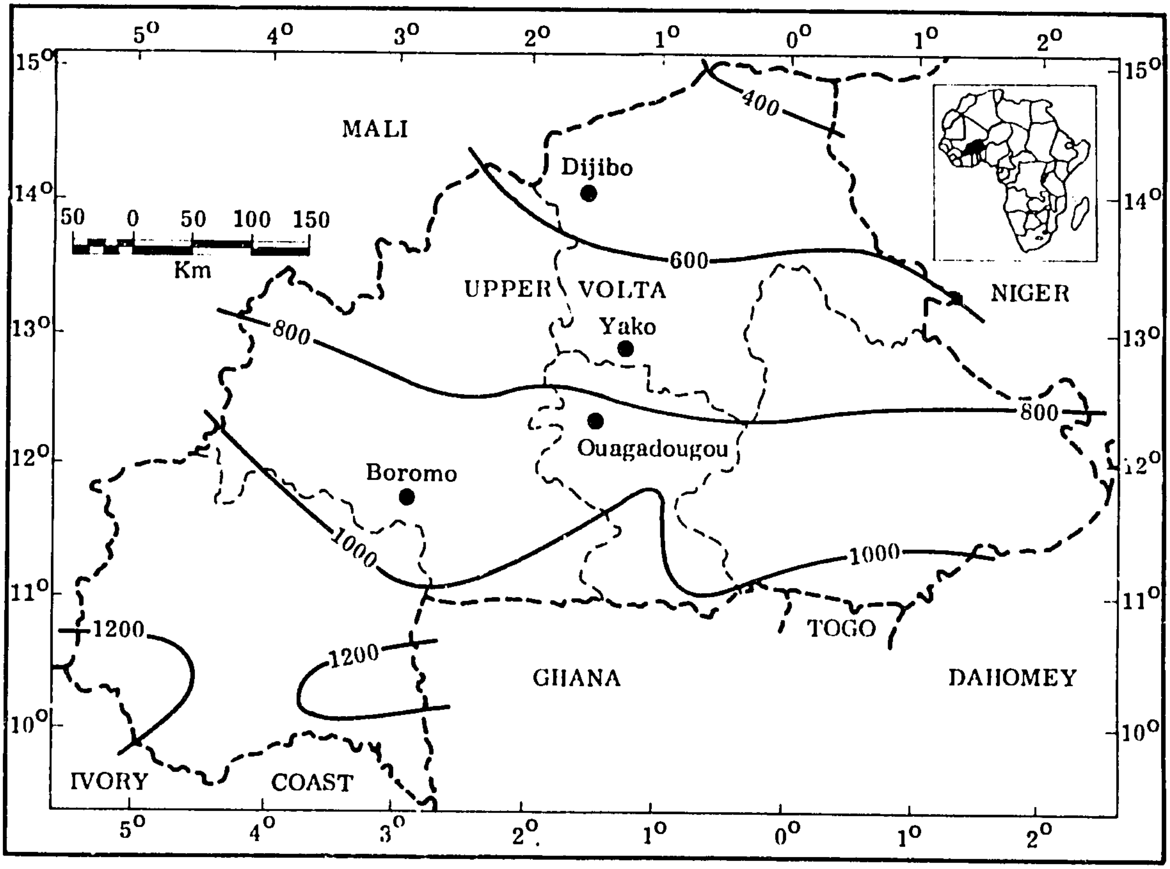


Figure 28. Mean annual rainfall (mm) in Upper Volta.

treatments will provide estimates of the reliability of rainfall over shorter periods.

Mean monthly rainfall and annual rainfall along with the standard deviation, coefficient of variation, maximum and minimum rainfall, and the range in rainfall recorded for each month, have been computed from daily rainfall data for all the 81 locations in Mali. From these, we have calculated seasonal rainfall for several representative locations in Mali (Table 32). This shows clearly the monomodal distribution of rainfall, which is the result of the seasonal movement of the intertropical convergence zone (ITCZ).

Weekly average meteorological data for the computation of Penman potential evapotranspiration (PE), made available for 9 locations by the Mali Meteorological Services, were used to compute potential evapotranspiration. From this data, we have computed water balances for 9 locations (Table 33).

Table 30. Mean monthly and annual rainfall (mm) at 4 selected locations in Upper Volta.[1]

	Location			
Month	Boromo	Ouagadougou	Yako	Djibo
January	0	0	0	0
February	2	1	0	0
March	9	4	4	2
April	33	23	16	5
May	89	71	48	23
June	118	102	94	59
July	197	171	179	129
August	269	235	230	190
September	184	132	140	102
October	50	30	29	28
November	8	3	2	3
December	2	0	1	0
Annual	961	541	743	772

1. Based on 55, 65, 36, and 26 years of rainfall data for Boromo, Ouagadougou, Yako, and Djibo, respectively.

Table 31. Minimum amounts of seasonal rainfall expected for each of 4 different probabilities, at 4 selected locations in Upper Volta.[1]

Location	Length of growing season (days)	Season[3]	Dates	Minimum amount of rainfall expected (mm) Probability (%)				Mean[2] rainfall (mm)
				90	75	25	10	
Boromo	174	Dry	5 Nov-18 Mar	0	2	18	34	12
		Prerainy	19 Mar-13 May	20	35	94	134	69
		Rainy	14 May-14 Oct	382	551	1097	1429	860
		Postrainy	15 Oct - 4 Nov	1	5	32	58	22
Ouagadougou	167	Dry	5 Nov- 8 Apr	1	2	15	27	10
		Prerainy	9 Apr -20 May	9	21	80	126	57
		Rainy	21 May-30 Sept	313	443	857	1105	676
		Postrainy	1 Oct - 4 Nov	3	8	45	76	31
Yako	160	Dry	5 Nov-15 Apr	1	2	16	29	11
		Prerainy	16 Apr -27 May	10	20	65	98	47
		Rainy	28 May-30 Sept	495	565	741	831	656
		Postrainy	1 Oct - 4 Nov	4	10	43	69	30
Dijibo	125	Dry	22 Oct -29 Apr	14	24	64	90	47
		Prerainy	30 Apr -17 Jun	14	24	64	90	47
		Rainy	18 Jun -22 Sept	302	362	521	606	449
		Postrainy	23 Sept-21 Oct	4	11	56	94	39

1. Based upon 55, 65, 36 and 26 years of rainfall data for Boromo, Ouagadougou, Yako, and Djibo.
2. Growing season = rainy plus postrainy seasons.
3. Seasons are considered as dry, prerainy, rainy, and postrainy when the probability of getting at least 10 mm of rainfall is 0 to 15%, 15 to 45%, 45 to 100%, and 45 to 15% respectively.

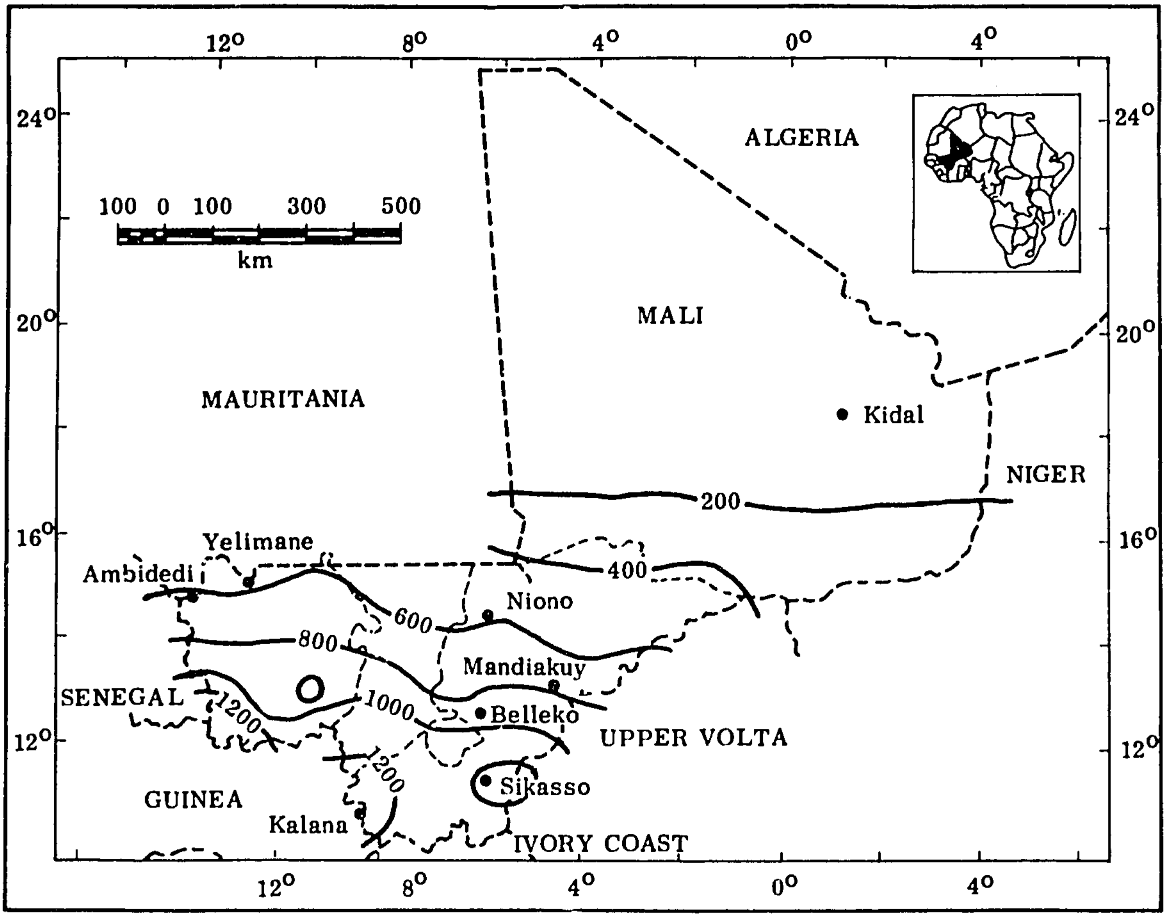


Figure 29. Mean annual rainfall (mm) in Mali.

Table 32. Seasonal rainfall (in mm) at some selected locations in Mali.

Station	Prerainy	Rainy	Postrainy	Dry	Annual
Kidal	12.5	45.7	49.1	28.7	136.0
Yelimane	14.6	515.7	23.7	15.9	569.9
Niono	26.5	506.5	22.7	16.7	572.4
Ambidedi	34.7	639.7	23.4	6.0	703.8
Mandiakuy	39.5	697.3	14.1	19.3	770.7
Belleko	55.4	823.5	26.6	14.3	919.8
Kalana	33.9	1152.4	43.7	15.8	1245.8
Sikasso	52.9	1225.3	-	27.4	1305.6

Toposequence Studies: Upper Volta

In 1983, we concluded our initial 5-year program, which analyzed farmers' traditional agricultural systems in Upper Volta and began experiments aimed at improving productivity. Initially, on-station research was carefully located on different soils at Kamboinsé Research Station to provide information directly related to similar soils in farmers' fields. Subsquently, increased emphasis was given to on-farm research by the location of experiments in the study villages of the Socioeconomics subprogram, after that commenced in 1980. This report gives a summary of some of our major findings; especially important is the role of the different soils in the landscape.

The traditional agricultural systems in the 500-700 mm rainfall zone (North Sudanian zone) are not very productive. Average cereal yields are about 500 kg grain/ha. But, yields

Table 33. Length of growing season (weeks) for soils of different water-holding capacities, for indicated locations in Mali.

Location	Soil water-holding capacity, mm	Growing season, season, weeks
Kayes	120	19
	190	21
Segou	120	17
	190	19
San	120	19
	190	20
Nioro-du-Sahel	120	15
	190	15
Bamako-Ville	150	24
	200	24
Sikasso	60	27
	250	32
Bougouni	60	27
	250	28
Mopti	100	14
	270	16
Tombouctou	40	2
	110	0

were reliable from year to year, despite the variable rainfall and soils with low fertility and low water-holding capacity. This stability of productivity, important for subsistence farmers, is attributed to at least three factors:

1. the farmers' use of management practices and choice of crops that are adapted to different soils;
2. intercropping;
3. a range of cultivars for each crop.

We recognize that these factors need to be preserved in improved systems.

The different soils occur in regular patterns or sequences, according to topography. A typical toposequence consists of shallow light-textured soils over hard laterite in the uplands and upper slopes; deeper profiles, but still with light-textured surface soils, in the middle slopes; and deep heavier-textured soils in the lowlands, which additionally are prone to temporary waterlogging or flooding.

Considerations of the expected moisture regime during the growing season, in conjunction with the water-holding capacity of the soil, indicate how the farmer has adapted his choice of crops and management practices to fit his environment. Millet is grown on the uplands and upper slopes, sorghum on the middle and lower slopes, maize on the lower slopes, and rice in the lowlands. The soil moisture regime at a given point in a toposequence will differ between seasons due to variability in rainfall. Risks of total failure of a single crop are minimized by the farmers' common use of intercrops. Examples for the cereals are millet/sorghum in the middle to upper slopes, and sorghum/maize in the lower slopes.

Detailed studies of the soils in representative toposequences have been made in association with the Royal Tropical Institute, Amsterdam. Analyses of the soils have shown the generally low level of nutrients in the soils; nutrient status and clay content increased downslope.

Responses to added fertilizer along the slope show that soil fertility may also play a role in the choice of crops, in addition to moisture regime. The fertilizer treatment involved addition of N, P, and K to all crops at seeding (14, 10, and 12 kg/ha), followed by a side-dressing of urea (30 kg N/ha) to the cereals, after emergence. Sorghum responded to fertilizer, especially on the midslope, when it followed cowpea in a simple 2-year rotation of cowpea-sorghum (Fig. 30). A similar 2-year rotation for millet (cowpea-millet) showed that the better growth of millet on the midslopes and lowerslopes, than on lowlands, was not due to nutrient-supply; we assume that waterlogging was the primary cause.

Another series of experiments on the Nakomtenga toposequence showed that yields of sorghum and millet were similar in the upland position, that both increased downslope to a maximum at the midslope position, then decreased in the lowlands (Table 34). Nevertheless sorghum yields in the lowlands were lower than those in the uplands. There were general

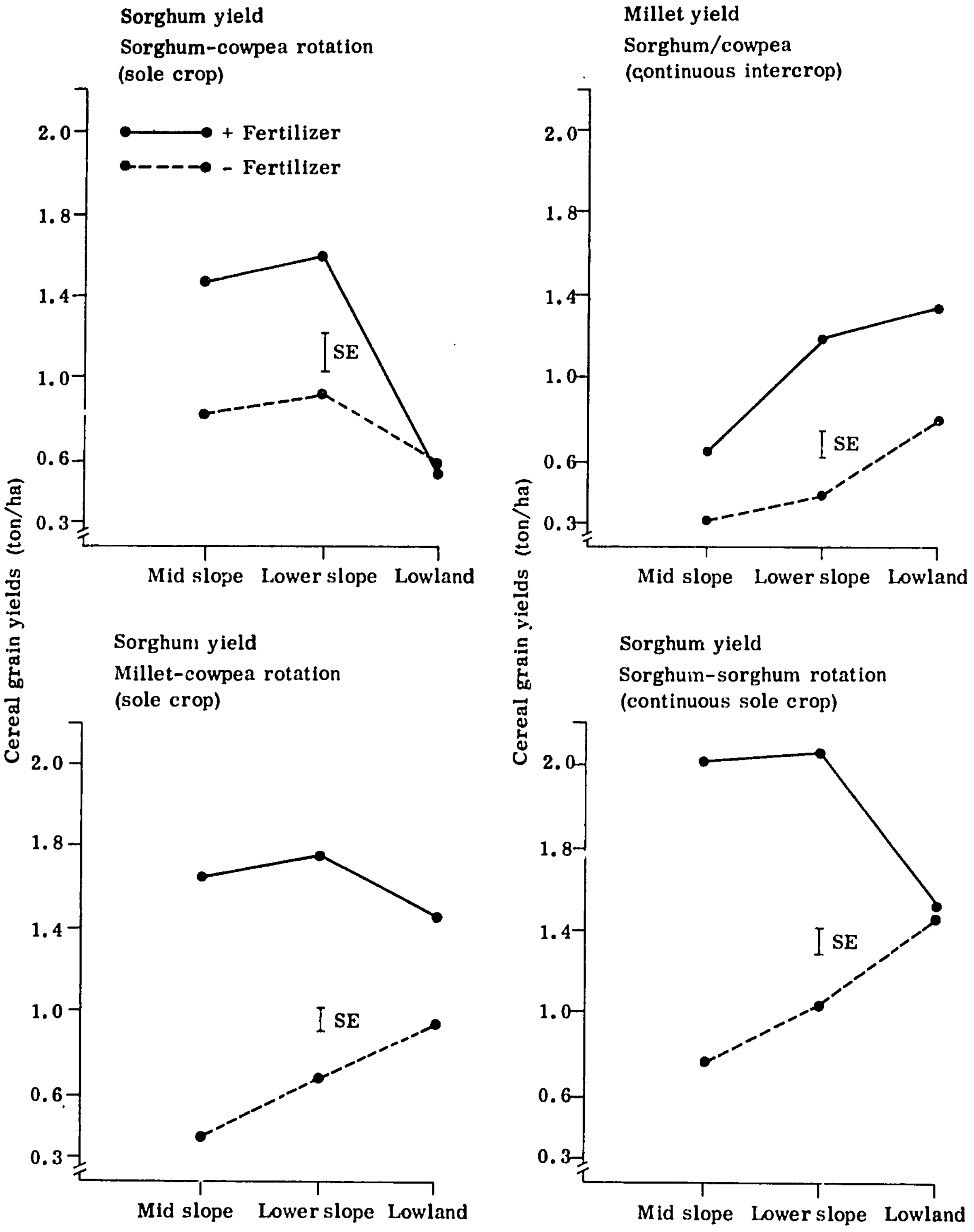


Figure 30. Sorghum and millet grain yield responses for different cropping systems/rotations when grown on three land types with and without fertilizer (means of 3 years of experimentation) Upper Volta.

Table 34. Grain yield responses of millet and sorghum to NK fertilizer treatments applied on four different toposequence positions in the Nakomtenga village.

	Grain yields (kg/ha)	
	Sorghum	Millet
Land types		
Upper slope	1200	1160
Midslope	1380	1200
Lower slope	2200	1450
Lowland (periodically inundated)	1530	890
SE	±116	±85
NK fertilizer responses		
Nitrogen (N)		
15 kg N/ha	1490	1080
45 kg N/ha	1660	1270
Potassium (K)		
12.5 kg K/ha	1460	1160
37.5 kg K/ha	1690	1190
SE	±82	±60
CV (%)	14.8	14.5

marginally significant responses ($P<0.10$) by sorghum to added potassium, and by millet to added nitrogen. Phosphatic fertilizer (10 kg P/ha) had been added as a basal dressing to the whole experimental area.

In this area, the lower and middle slopes are approaching a high intensity of cultivation, and the major pressure is for increasing intensity of cropping on the upper slopes and uplands. The data in Figure 30 indicate that nutrient inputs on the uplands may allow extension of sorghum cropping further upslope than is currently practiced. However, because of the less assured moisture regime on these shallower soils, we need improved sorghum cultivars with a maturity about 10 days earlier than existing cultivars, to ensure maturity before moisture supplies are depleted at the end of the rainy season. For this, photosensitive cultivars will be needed, to ensure reliability in maturity date whilst allowing flexibility in time of establishment due to the unreliability of rains earlier in the season. The value of these approaches is that they indicate the importance of considering edaphic and agroclimatic components in any crop-improvement program.

Component Research

Millet Agronomy: Niger

The millet production agronomy program at the ICRISAT Sahelian Center (ISC), Niger, has initiated work in three areas; basic millet agronomy, millet-based intercropping systems, and crop establishment. Information from the first two is presented.

To identify and test solutions to constraints to millet production in the southern Sahelian zone, we studied improved millet varieties, increased plant density, improved soil fertility, and alternative intercropping systems.

Improved varieties. Improved varieties introduced into the millet production system under moderate fertility have given disappointing results over the last 3 years, including 1983, even though soil moisture was above average throughout the season. In a trial that included improved cultivars from Nigeria, Mali, Niger, and Senegal under adequate fertility (45 kg N/ha and 17 kg P/ha), the local cultivar (Sadoré local) produced the highest grain yield (Table 35). The trial yields of some of the cultivars, mostly improved locals (HKP, P3 Kolo, ITV 8001, Sanio Mali), did not differ significantly ($P>0.05$) from the top yielder. The local cultivar generally was taller and leafier, and had a high total dry-matter production. The improved local cultivars had better harvest indices than the local cultivar or the later-flowering varieties (Souna III and Sanio Mali). Breeders obviously have selected for earlier flowering in the improved cultivars but it appears that growth rate has been sacrificed to early flowering, resulting in less vegetative growth and a smaller potential sink size. During 1984 we will investigate whether growth rate during the vegetative stages to flowering and days to flowering affect yield potential.

Table 35. Comparison of 12 improved millet cultivars at ISC, Niger, 1983.

Genotype	Days to 50% anthesis	Days to maturity	Grain yield (t/ha)	Total biomass (t/ha)	Harvest index
Local (Sadoré)	78	116	1.66	9.03	0.19
HKP	61	102	1.56	6.47	0.24
P3 Kolo	61	109	1.45	6.65	0.22
ITV 8001	63	102	1.38	6.07	0.23
Sanio Mali	81	112	1.36	9.74	0.14
Souna III	70	105	1.30	6.65	0.20
CIVT	60	102	1.28	5.50	0.24
3/4HK	62	104	1.28	5.50	0.23
IBV 8004	61	102	1.11	5.61	0.21
ICMS 7819	61	99	1.04	4.59	0.23
Souna Mali	64	105	0.80	3.37	0.23
MBH 110	55	98	0.69	3.23	0.21
SE	±0.8	-	±0.10	±0.55	±0.013
Mean	65	-	1.24	6.03	0.21
CV (%)	3	-	21	20	14

Water use (0-130 cm soil depth) and maximum light interception of the local cultivar was higher than that of improved cultivars; but, water-use efficiency (WUE) of the local cultivar, measured as grain yield per mm of water used, was lower than that of HKP, P3 Kolo, and CIVT 3 (Table 36). However, water-use efficiency of the local cultivar, measured by total dry-matter production per mm of water, was similar or better than that of improved lines. The improved local cultivar, HKP, had the highest water-use efficiency for both grain production and total dry matter. It appears that selection should be aimed at improving the partitioning of dry matter to grain production of local cultivars, while maintaining their total dry-matter production.

Farmer-managed tests on village fields in 1982 showed that the improved variety was no better than the farmer's cultivar. So a researcher-managed, on-farm trial was conducted at two villages this year to compare the performance of released and prelease cultivars in farmers' fields, with research level management. The results, based on 10 replications of 36 square meter plots, showed no significant differences for grain yield between the improved and farmer's cultivars or among improved cultivars. Actual variety yields differed as much as 20% but because of variation in the experimental rate, these differences were not statistically significant. Additional research (on field testing of designs and replications) will be carried out to improve preci-

Table 36. Water use and radiation interception by 12 millet cultivars at ISC, Niger, 1983.

Cultivar	Water use during growing period (mm)	WUE (kg/ha per mm) for Grain yield	WUE (kg/ha per mm) for Total DM	Maximum radiation interception (%)
Local cv	291	5.70	31.0	68
HKP	215	7.26	30.1	59
P3 Kolo	214	6.78	31.1	54
ITV 8001	224	6.16	27.1	60
Sanio Mali	279	4.87	34.9	61
Souna III	207	6.28	32.1	62
CIVT	190	6.74	28.9	58
3/4 HK	219	5.84	25.1	54
IBV 8004	232	4.78	24.2	60
ICMS 7819	174	5.98	26.4	57
Souna Mali	218	3.67	15.5	54
MBH 110	140	4.93	23.1	46

sion as a 20% yield difference if real, does represent an acceptable return to several cycles of rotation.

Improved soil fertility. Millet grain yields have responded markedly to added fertilizer, particularly to phosphate, at the ISC. We also found that with added fertilizer, plant populations can be increased. Both findings were used in a researcher-managed on-farm trial to test yield gains in farmers' fields with different varieties, cropping systems, and management levels. The released, improved cultivar, CIVT, and the farmers' local cultivar were compared, as sole crops and as traditional millet/cowpea intercrops. Two levels of management were employed: without added fertilizer at traditional plant populations (4400 hills/ha), and with added fertilizer at 10000 hills/ha.

Table 37. Results from agronomy trials at Gobery (260 mm) and Sadeze Koira (361 mm) in eastern Niger, 1983.

	Millet grain yield (kg/ha)		Cowpea hay yield (kg/ha)	
Treatment	G[1]	SK[1]	G	SK
Management				
No added N,P 1.5×1.5 m spacing	281	321	244	121
Added N,P 1×1 m spacing	1155	689	300	293
SE	±83	±132	±70	±55
Cropping system:				
Sole millet	722	546	0	0
Millet/cowpea intercrop	694	464	272	206
SE	±46	±80	-	-
Millet variety:				
Local cultivar	705	477	291	192
CIVT	712	532	253	222
SE	±54	±77	±38	±26

1. G = Gobery, SK = Sadeze Koira

Millet grain yields were significantly ($P<0.05$) increased by the fertilizer and higher plant population at both Gobery and Sadeze Koira and cowpea hay yields were increased at Sadeze Koira (Table 37). Intercropping did not significantly reduce millet grain yields at either location, but the trend toward lower yields is consistent with previous findings (ICRISAT Annual Report 1982). However, the lower millet yields were more than offset by the value of additional cowpea hay. As in the other on-farm trials, the improved cultivar did not significantly outyield the local cultivar. We concluded that yield increases from added fertilizer and higher plant population can be transferred to farm-level conditions.

Intercropping. The traditional millet production system in the southern Sahelian zone is millet intercropped with indeterminate or vining cowpea (*Vina unguiculata*); the cowpea is used largely for hay. Intercropping intensity is generally very low. We started a long-term trial using added fertilizer and different proportions of cowpea in the intercrop, to examine the effects of the cowpea proportion on the maintenance of soil nitrogen status and grain yields. Nearly half of the rainfall in 1983 at ISC (619 mm) fell in the first 4 weeks after planting, so yields were low, probably due to nutrient leaching.

Still the added fertilizer increased grain millet yields significantly ($P<0.05$) in both the intercrop and the sole crop (Table 38). Cowpea hay yields increased significantly ($P<0.05$) with increased proportions of cowpea in the intercrop, without significantly decreasing millet grain yields. This contrasts with previous results, so further testing is needed. Millet grain yield from the intercrop treatments averaged 68% of millet alone. Adding fertilizer did not affect land equivalent ratio (LER) values, indicating that the growth of both crops was promoted similarly (Table 39). Although the LER for millet grain yields stayed relatively constant across intercropping proportions, cowpea LER values increased significantly ($P<0.05$) with increased cowpea proportion. Total LERs indicated a general yield advantage to intercropping.

Table 38. Results of the first year of a long-term cropping systems experiment planted at Sadoré in 1983.

Treatment	Sole millet grain (kg/ha)	Sole cowpea hay (kg/ha)	Intercropped: millet grain (kg/ha)	Intercropped: cowpea hay (kg/ha)
Fertilizer levels:				
None applied	316	1218	207	634
Added N&P[1]	558	1598	387	764
SE	±42	±188	±46	±64
Intercropping proportions:				
Millet/cowpea 6:1	-	-	342	598
Millet/cowpea 3:1	-	-	276	516
Millet/cowpea 2:1	-	-	291	758
Millet/cowpea 1:1	-	-	278	927
SE			±61	±113

1. Fertilizer rates were 65 kg/ha of urea and 100 kg/ha of single superphosphate.

Sorghum Agronomy: Nigeria

The objective of our Agronomy Program in Nigeria, initiated in 1983 and supported by SAFGRAD, is to develop improved sorghum-based farming systems. Our approach is to extend cropping from the onset of rains as far as possible into the postrainy season, by utilizing improved sorghum cultivars and systems associated with them.

During the first year of this program, emphasis was therefore given to evaluating and selecting appropriate sorghum cultivars with wide adaptability, so that these could form the basis for developing alternate cropping systems for the different environments where sorghum is grown in West Africa. Also, field trials were conducted to determine improved agronomic practices, e.g. crop density and crop nutrition, needed for optimizing productivity. Cropping systems research was initiated to examine the performance of promising genotypes in various mixed cropping systems.

Genotype evaluation. Improved tropical sorghum genotypes made available from ICRISAT, and Indian and Nigerian national breeding programs, were evaluated at two locations in northern Nigeria. Both locations received only about 60% of normal rainfall; Samaru received only 617 mm (normal 1087 mm).

Because rains ceased suddenly during September, most traditional and improved (long-season) sorghum cultivars in the area produced little grain. In our experiments, all improved genotypes performed well (Table 40). At Kano, early maturity was the particular characteristic of the higher-yielding cultivars. Most of the high-yielding genotypes were photoinsensitive, early maturing (about 70 days to flowering), and short statured (less than 2 m tall). Their grain quality did not seem inferior to that of local cultivars. Genotypes such as S 34, S 35, S 20 and K 4 will be considered as replacements for the traditional late-maturing sorghums in designing more productive cropping systems.

Agronomy of altered sorghum genotypes. We carried out studies on the relationship between crop density and genotypes. The recommended plant population for local sorghums in Nigeria is about 50000 plants/ha. By increasing crop den-

Table 39. Land equivalent ratios from the long-term cropping systems experiment at Sadoré in 1983.

Factor indicated	Millet grain LER[1]	Cowpea hay LER	Combined millet and cowpea LER
Fertilizer levels:			
None added	0.66	0.52	1.18
Added N&P	0.69	0.48	1.17
SE	±0.13	±0.05	±0.16
Intercropping proportions:			
Millet/cowpea 6:1	0.79	0.47	1.23
Millet/cowpea 3:1	0.59	0.37	0.96
Millet/cowpea 2:1	0.65	0.54	1.19
Millet/cowpea 1:1	0.66	0.66	1.32
SE	±0.13	±0.05	±0.14

1. Land equivalent ratios were calculated using trial means for the sole plots.
2. See table 38 for the fertility treatments.

Table 40. Performance of some promising sorghum genotypes, Nigeria, 1983.

		Samaru[1]			Kano[2]		
Genotype	Pedigree	Days to flower	Plant height (cm)	Grain yield (kg/ha)	Days to flower	Plant height (cm)	Grain yield (kg/ha)
K 4	M 36037	65	197	2870	68	161	2270
S 35	M 91019	65	187	2520	65	171	2760
BES	Improved Nigerian variety	66	182	2850	65	160	2360
S 13	SPV 313	68	160	3200	70	152	1410
S 20	SPV 315	70	160	3120	75	122	1410
S 32	A 6213	70	180	3350	75	144	1450
S 34	SEPON 183 ('80 Nursery)	70	192	3890	76	150	1300
Local (Improved)		105	208	2460	80	150	880
Local (Farmer variety)		111	370	840	100	198	220
SE			±6.0	±180		±10.0	±360

1. Northern Guinean zone, normal rainfall 1087 mm, 1983 rainfall 617 mm.
2. Sudanian zone, normal rainfall 700 mm, 1983 rainfall 409 mm.

sity up to 75000 plants/ha, we significantly increased the grain yields of all early-maturing, short varieties, at both Samaru and Kano. The shape of the yields vs density relationships indicated that local and local improved (late-maturing genotypes) gave maximum yields at about 75 000 plants/ha, but that the optimimum density for the improved early-maturing genotypes would have been higher. At both Samaru and Kano the altered genotypes (S 34, S 20, S 35) outyielded the local and local improved at all density levels and respond better at higher densities.

Experiments were also conducted to investigate responses of sorghum genotypes to various nitrogen fertilizer rates. Three genotypes examined in the density × genotype studies were also evaluated under four fertilizer-N rates (0, 35, 70, and 105 kg/ha). A basal dressing of 17 kg P/ha and 33 kg K/ha was applied to all treatments before sowing. The nitrogen was applied in split doses 3, 6, and 9 weeks after sowing.

Tables 41 and 42 show the response of the cultivars to different amounts of fertilizer-N added at Samaru (Northern Guinean zone) and Kano (Sudan zone). At Samaru, grain yields of the improved local and the earlier maturing, short-statured cultivar were increased substantially by the first increment (35 kg N/ha) of fertilizer-N but not by subsequent increments. The farmers' local cultivar did not respond to moderate application rates of N, and the highest rate of fertilizer-N caused a marginally significant ($P < 0.10$) decrease in yield. At the highest N rates, the improved cultivars gave substantially higher yields than the farmers' local. The later maturity of the farmers' local cultivar caused it

Table 41. Grain yields (kg/ha) of 3 sorghum cultivars at four application rates of fertilizer N, Samaru, 1983.

	N-rates (kg/ha)				
Cultivar	0	35	70	105	Mean
Local	950	910	900	460	800
Improved	680	1460	1330	1360	1270
Altered	880	1170	1400	1470	1230
Mean	840	1180	1290	1100	1100

SE for comparing 2 levels of nitrogen ±89.
SE for comparing 2 cultivars ±131.
SE for comparing 2 rates of nitrogen for the same cultivar ± 180.
SE for comparing 2 cultivars at same rate of nitrogen ± 173.

Table 42. Grain yields (kg/ha) of 3 sorghum cultivars at four application rates of fertilizer-N, Kano, 1983.

	N-levels (kg/ha)				
Cultivar	0	35	70	105	Mean
Local	170	420	320	400	330
Improved	320	500	480	370	420
Altered	510	560	520	510	520
Mean	330	490	440	430	420

SE for comparing 2 levels of nitrogen ±41.
SE for comparing 2 cultivars ±72.
SE for comparing 2 levels of nitrogen for the same cultivar ±95.
SE for comparing 2 cultivars at same level of nitrogen ±92.

to suffer more from drought stress due to the early cessation of the rains, and the drought stress was greater where nitrogen had been applied because of the increased vegetative growth.

At Kano, yields were lower because of the lower rainfall and greater drought stress during the rainy season. Nitrogen fertilization did not cause significant increases in grain yield, but the improved early-maturing, short-statured cultivar outyielded the farmers' local on the no-N treatment.

Intercropping experiments with sorghum. At Samaru in the 1983 rainy season we examined the performance of a number of improved sorghum genotypes when intercropped with a single millet genotype. Millet was planted with the first rains (last week of May), then sorghum was planted between the millet rows about 3 weeks later, as is the traditional practice in West Africa.

All the improved (early-maturing, short-statured) genotyes gave significantly (P<0.001) higher grain yields than the farmers' local when grown as sole crops, and all except S 20 gave substantially higher yields (P<0.10) when intercropped with millet (Table 43). However, intercropping with millet reduced the sorghum yield to less than 50%, on average, of its sole crop yield. Millet yields were less affected by intercropping, presumably because millet was planted ahead of sorghum. The yield advantage of intercropping sorghum with millet was 30%, on average, as shown by the total LER.

At Samaru the same improved sorghum genotypes were intercropped with groundnut. Sorghum was planted 2 weeks later than groundnut to allow groundnut establishment free of competition. Yields of both crops were reduced substantially under intercropping, and the yield advantage of intercropping averaged only 10% (Table 44). S 34 yielded best in both sole cropping and intercropping, but several improved cultivars gave yields similar to the local under intercropping.

Table 43. Performance of some improved sorghum genotypes when intercropped with millet, Samaru, 1983.

	Grain yield kg/ha					
		Intercrop				
Genotype	Sole	Sorghum/	Millet[1]	Sorghum LER	Millet LER	Total LER
S 20	1859	769	836	0.42	0.80	1.22
S 34	2584	1202	899	0.51	0.86	1.37
S 35	2540	1060	844	0.42	0.81	1.23
S 40	2119	1042	920	0.49	0.88	1.37
KSV 11	3103	1192	942	0.39	0.90	1.29
Local cv	827	508	722	0.60	0.69	1.29
SE	±214	±160				

1. Sole millet yield = 1045 kg/ha.

Table 44. Performance of some improved sorghum genotypes under intercropping with groundnut, Samaru, 1983.

	Grain yield kg/ha					
		Intercrop				
Genotype	Sole	Sorghum/	groundnut[1]	Sorghum LER	Groundnut LER	Total LER
S 20	1460	741	945	0.54	0.54	1.08
S 34	2122	1469	753	0.70	0.43	1.13
S 35	1447	958	912	0.70	0.52	1.22
S 40	1195	737	718	0.54	0.41	0.95
KSV 11	1710	1106	876	0.66	0.50	1.16
Local cv	1004	719	632	0.70	0.36	1.06
SE		±208	±192			

1. Sole groundnut pod yield = 1750 kg ha.

Soil Fertility: Niger

The soil fertility research program, which commenced in 1982 with funding from the International Fund for Agricultural Development (IFAD) through the International Fertilizer Development Center (IFDC), has emphasized the amelioration of the known major soil deficiencies of phosphorus and nitrogen. The research approach involves characterizing the nutrient needs for the major crop and soil combinations, identifying the most agronomically effective and economical fertilizers, and assessing how the combination of crops in various cropping systems influences nutrient needs.

Preliminary results show that applications of water-soluble phosphorus (WSP) consistently caused substantial increases in grain yield of both millet and cowpea. The method of fertilizer application determined its effectiveness, and fertilizer-P applied in one year had appreciable residual effects the following year. Finely-ground rock phosphate (RP) caused only small responses. However, partially-acidulated rock phosphate (PARP) was almost as effective as WSP. PARP is prepared by treating rock phosphate with only a fraction (25-50%) of the acid required to fully convert the relatively insoluble phosphate in RP to WSP.

Responses to nitrogen varied substantially between locations. Urea broadcast on the soil surface was more effective than placement close to the millet hills.

These preliminary results on the effectiveness of PARP are encouraging. In Niger, WSP is expensive because of high transport costs from distant ports, resulting in high costs of both fertilizers and the sources of acid required to prepare WSP from local rock phosphate deposits. The use of local deposits of rock phosphate to prepare PARP, and the reduced amounts of acid required (as the partially-acidulated material appears to be satisfactory), should substantially reduce the cost of preparing an effective P fertilizer.

Next year, we will extend our studies of rock phosphate and partially-acidulated rock phosphate to examine the effectiveness of these materials over a range of soil conditions and management practices, especially those in farmers' fields.

Soil and Water Management: Upper Volta

In 1982/83, our SAFGRAD-supported program continued basic studies at Kamboinsé on management techniques (tied-ridging and mulching) for improving conservation of soil moisture. We also conducted similar experiments in the Socioeconomics Program study villages, and collected information needed for designing soil and water management systems.

Millet at ICRISAT Sahelian Center, Niger, without (above) and with (below) applied phosphorus. Water-soluble phosphorus consistently caused substantial grain yield increases in both millet and cowpea, but is expensive because it has to be transported to the region. Locally-mined phosphorus has been processed and found promising.

Table 45. Effect of sorghum variety and quantity of mulch on grain yield (t/ha).

Sorghum variety	Quantity of mulch (t/ha) 0.0	7.5	15.0	Mean	SE
E 35-1	1.44	1.65	2.02	1.70	
Framida	1.84	2.41	2.71	2.32	±0.08
Local (Kamboinsé)	0.88	1.10	1.43	1.14	
SE		±0.14			
Mean	1.36	1.69	2.02		
SE		±0.03			

Table 46. Effects of millet variety and quantity of mulch on grain yield (t/ha).

Millet variety	Quantity of mulch (t/ha) 0.0	7.5	15.0	Mean	SE
Ex-Bornu	0.95	0.94	1.05	0.98	
Souna III	0.93	0.97	1.22	1.04	±0.04
Local	0.25	0.25	0.30	0.27	
SE		±0.08			
Mean	0.67	0.68	0.81		
SE		±0.04			

On-station research. The effects of organic mulches on grain yields of sorghum and millet were examined in separate experiments for each crop. Sorghum and millet stalks were added to the soil surface at rates of 0, 7.5, and 15 t/ha immediately after seeding on 20 June 1983, into recently cultivated and ridged soil. The ridges were 50 cm apart for sorghum and 100 cm apart for millet; they were "tied" at 1-m spacings after planting but before applying the mulch. After establishment of the crops, populations were thinned to 80000 and 96000 plants/ha for sorghum and millet respectively.

Under the basal tied-ridging management system, the two crops responded differently to mulching. Grain yields of all three sorghum genotypes were increased by mulching; the yield of the local Kamboinsé cultivar was lowest at all mulch treatments (Table 45). For millet however, mulching increased grain yield of only one cultivar (Souna III); as with sorghum, the local cultivar gave the lowest grain yield at all three rates of mulching (Table 46).

The 1983 season was particularly suitable for examining the effects of mulching on cereal growth. The total rainfall in that season was only 60% of the average, mainly because the rainy season ended abruptly about 3 weeks earlier than usual.

The presumption that mulching benefitted crop yields through effects on moisture conservation was given some support by results from parallel experiments on the same cultivars used in the mulching experiments examining the effects of stand density. The grain yield of two of the sorghum cultivars, E 35-1 and Framida, decreased as stand density increased above 88 000 plants/ha (Table 47), a result expected when

Table 47. Effect of sorghum variety and stand density (plants/ha) on grain yield (t/ha).

Sorghum variety	Stand density (plants/ha) 88000	110000	140000	220000	Mean	SE
E 35-1	1.83	1.35	1.33	1.15	1.42	
Framida	1.72	1.28	1.27	1.08	1.34	±0.08
Local	0.72	0.72	0.74	0.81	0.75	
SE		±0.13				
Mean	1.41	1.12	1.11	1.02		
SE		±0.10				

Table 48. Effects of millet variety and stand density (plants/ha) on grain yield (t/ha).

Millet variety	Stand density (plants/ha) 40000	50000	67000	100000	Mean	SE
Ex-Bornu	2.16	2.01	1.90	1.73	1.95	
Souna III	2.34	2.38	1.91	1.68	2.08	±0.10
Local	0.50	0.51	0.48	0.47	0.49	
SE		±0.13				
Mean	1.53	1.50	1.33	1.21		
SE		±0.23				

moisture limits growth and grain development. However, grain yield of the local sorghum cultivar did not decrease with an increase in density, in contrast to its response to mulching. For millet, the increase in yield of Souna-III and the lack of an increase by the local, as density decreased, were in agreement with the beneficial effects of mulching (Table 48). However, the increased yield of Ex-Bornu with decreasing stand density contrasted with the lack of a significant effect of mulching.

Mulch on these Alfisols reduces the amount of weeding necessary. During rainfall, the surface of unprotected soil puddles and it seals readily. Within the micro-catchment areas created by the tied ridges, water may pond 2 to 3 days after a rain; the environment is extremely poor for seedling growth and development, so weed control is easier. A mulch reduces the need for weeding, without the ponding and puddling associated with tied-ridges not mulched, thus facilitating better infiltration of water into the soil.

On-farm research. In the farmers' fields at Djibo, we examined types of soil-surface treatments similar to those investigated at the Kamboinsé station. The soil-surface treatments were: (a) tied-ridges, (b) tied melon-beds, (c) traditional flat planting, and (d) flat planting with tied ridges made during the first weeding by animal traction. In addition, we gathered measurement data for future plant-management studies in the region.

The short-statured, rapid-growing IKMV 8201 cultivar of millet was planted in pockets of 40 000 plants/ha in rows 100 cm apart. The entire field was plowed by animal traction and, where needed, ridged before seeding and tying. Table 49 presents the mean and standard deviation for the grain yield (t/ha).

A severe storm on 4 August caused runoff from fields above the study area and seriously eroded some plots. However, the runoff flowed over the traditional flat planting without serious erosion or plant damage. The storm occurred before the first weeding so the flat/tied-ridge, soil-surface plots were not damaged.

Table 49. Effects of indicated soil surface treatment on millet yield (t/ha) at Djibo, Upper Volta, 1983.

Soil surface treatment	Millet yield (t/ha) Mean	SD
Tied ridge	1.92	0.39
Melon beds	1.77	0.14
Flat	1.87	0.18
Flat/tied ridge	2.14	2.29

Workshops, Conferences, and Seminars

Meeting on Farming Systems/Environmental Guidelines

Sponsored by UNEP and coordinated by ICRISAT, this meeting was held 20-23 June at ICRI-

SAT Center. Case studies were presented, and environmental protection guidelines related to farming systems work in the arid, semi-arid, and humid tropics were developed. The meeting focused on increasing food production through improved farming systems while controlling degradation of soil in the areas concerned. Nine participants from UNEP, IRRI, IITA, FAO, Bulgaria, Egypt, Thailand, and India, and six from ICRISAT took part in the deliberations.

International Symposium on Minimum Data Sets for Agrotechnology Transfer

Jointly sponsored by ICRISAT, the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) of the University of Hawaii, and the Soil Management Support Services (SMSS) of the Soil Conservation Service United States Department of Agriculture (USDA), the symposium was held 21-26 March at ICRISAT Center. Ten ICRISAT scientists, and 57 others from Australia, Brazil, Burundi, Cameroon, China, Colombia, Costa Rica, Ecuador, Fiji, France, Guam, India, Indonesia, Malaysia, the Netherlands, Pakistan, Panama, Philippines, Syria, and Thailand participated. They discussed problem in experimental design to generate data for development and listing of crop models. Proceedings of the symposium are in press and will be available from Information Services, ICRISAT.

Workshop on Watershed-Based, Dryland Farming in Black and Red Soils of Peninsular India

This workshop, organized jointly by the National Bank for Agriculture and Rural Development (NABARD), the Indian Council of Agricultural Research (ICAR), and ICRISAT, was held 3-4 October at ICRISAT Center. Seventy-three senior officials--drawn from the departments of agriculture of the Government of India and the states of Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra, ICAR, NABARD, and other leading banks including 11 members of ICRISAT staff participated in the workshop. They endorsed the development of small agricultural watersheds as

Indian bankers and policymakers get an on-the-spot briefing on ICRISAT's dryland technology options during the workshop sponsored jointly by NABARD, ICAR, and ICRISAT.

a key element in improving dryland agriculture, recognizing that the major limiting factor to agricultural production in dryland areas is water, not land. Proceedings are available from Information Services, ICRISAT.

Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils

Fourteen specialists from Australia, Botswana, Federal Republic of Germany, India, the Netherlands, and USA and 26 ICRISAT scientists participated in the workshop, 30 November-3 December, to discuss constraints to increased productivity and to assess the current practices on effective management of tropical red soils under rainfed conditions. Discussion topics were the inventory and properties of Alfisols and related soils in the SAT, their agroclimatic characteristics, their management and conservation requirements, and cropping alternatives.

It was agreed that the diversity of the soils and agro-environments is so wide that no single strategy is likely to be universally successful for increasing crop productivity. Rather, systematic efforts to develop and test promising management components and combinations need to be conducted at different locations. The workshop recommended a cooperative research network approach. A synthesis document summarizing the proceedings is in press and the full workshop proceedings are in preparation, both will be available from Information Services, ICRISAT.

Workshop on Farmers' Participation in the Development and Evaluation of Agricultural Technologies

The ICRISAT West Africa Economics Program, assisted through partial funding from International Development Research Centre (IDRC), held this workshop 20-25 September in Ouagadougou, in collabration with the Organization of African Unity/Semi-Arid Food Grains Research and Development (OAU/SAFGRAD) Farming Systems Unit and Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT). The workshop assembled 60 researchers from some 20 countries in Africa, Latin America, North America, Asia, and Europe to discuss methods to more effectively involve farmers in technology development and evaluation. Workshop participants represented a broad range of experience; there was nearly equal representation of technical and social science disciplines, and of French and English backgrounds.

Workshop papers and discussion were organized around four themes: theoretical and practical problems in establishing valid communication between researchers and farmers; farmers' input in the diagnosis of existing farming systems; involving farmers in evaluating prospective technologies; and farmers' participation in the modification and design of new technologies. The workshop included field visits to sites in three zones of Upper Volta where on-farm research is being conducted by ICRISAT, SAFGRAD, and IRAT. The proceedings are to be published by IDRC in French and English and will be available in 1984.

Looking Ahead

Soil physics and conservation. The collection of baseline data for quantiative assessment of soil loss and runoff potentials will continue for important SAT soils. SAT Alfisols will be the primary target of interdisciplinary research to develop effective practices for optimized productivity and soil and water conservation and management. Land and soil treatments that impart long-term residual effects through improved soil structural characteristics will receive more emphasis.

Cropping systems. Studies will be initiated to determine factors contributing to efficient use of light by groundnut intercropped with different canopy crops. In cereal/pigeonpea intercropping a further study will be undertaken to study the competitive effects of pigeonpea on performance of sorghum vs millet as an intercrop, especially in the context of different moisture and nutrient regimes. An experiment is being initiated on a deep Vertisol at ICRISAT Center to evaluate the long-term effects of rotations of different cropping systems. On-Center operational-scale experiments will continue to evaluate alternate cropping systems on deep, medium, and shallow black soils and on Alfisols under low and high fertility. Cropping system evaluations will continue at Begumganj in Madhya Pradesh and Talod in Gujarat. We will initiate another operational-scale study at Phanda Farm in Madhya Pradesh, to evaluate alternate cropping systems on broadbed-and-furrows and flat-cultivated land on grade.

Soil fertility. Our first priority will be major studies of nutrient × water interactions, especially nitrogen, to assess the major sources of inefficiency in use of fertilizer. Continued work on the benefits of legumes, especially quantification of N-fixation rates in the field, and the way to include legumes in cereal systems, is clearly indicated. The preliminary studies of the behavior of P need to be followed by more detailed studies. Our long-term experiments on K and P willl continue, and an experiment is being initiated in conjuction with the Cropping Systems subprogram on the rotations for deep Vertisols that will maintain fertility.

Land and water management. The on-farm evaluation of land management techniques will be continued. We plan to increase our efforts in the interdisciplinary areas of water resources development, supplemental irrigation, and tillage.

Agroclimatology. We will continue efforts to provide meaningful evaluation of climate to outline cropping potentials for different regions. Collaborative research on the soil-plant-atmosphere continuum emphasizing response of crops to drought stress, evapotranspiration-yield relations, temperature-yield relations, and water-use efficiency will be continued. We will also continue efforts to collect standard data sets to develop and validate pearl millet and groundnut simulation models with particular emphasis on understanding pearl millet's tillering behavior. Applications of sorghum and pearl millet models to assess their production potentials in a range of agroclimatic environments will receive increasing attention.

On-farm evaluation of deep Vertisol technology. This will be extended to different agroclimatic environments. Emphasis will be laid on the evaluation of alternate land and water management practices, appropriate cropping systems, and plant protection measures.

On-farm locations will be used for analyzing the constraints to the introduction of improved farming systems of poor Vertisols. These locations will also be used for training of extension workers and farmers to facilitate the diffusion of improved technology, and will serve as an important source of feedback for the scientists.

Farm power and equipment. We will continue with field experiments on interrow weed management and fertilizer placement. These are required to provide information to carry out design modifications of existing equipment. We aim to develop a 4-row planter unit which can be used without a WTC. This development will particularly help farmers who wish to improve upon planting techniques but who do not intend to purchase a tool carrier.

Efforts will be made to develop equipment mounted on the WTC for applying agrochemicals to tall crops, especially pigeonpea. This will involve evaluation of various technological options (dusts as well as sprays), and pesticide formulations in the labora

Performance studies of improved animal-drawn equipment in on-farm situations will continue. Information from such research will help in the final testing of improved machinery systems developed to assist SAT farmers, and identifying areas for further research and development.

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Contents

Technology and Policy Assessment 311
- Farmers' Tests of Technology in Upper Volta 311
  - Evaluation of Sorghum and Millet Varieties 312
  - Economics of Fertilizer Use 313
  - Effects of Contour Bunds on Grain Yields under Farmers' Management 314
- Farmers' Tests in Niger 315
- Whole-Farm Constraints to Adopting Improved Vertisol Technology 315
- Technological Change in Indian SAT Agricultural Markets 318

Behavioral Studies 321
- Determinants of Individual Diets and Nutritional Status in 6 Indian SAT Villages 321
- Consumption and Nutritional Patterns of ICRISAT Mandate Crops in India 324
- Describing Production and Marketing Patterns in Upper Volta 326
- Assessing Socioeconomic Change in Upper Volta 328
- Variations in Productivity among Upper Voltaic Farmers 330
- Management Variation and Its Determinants in India's SAT 332
- Income Fluctuations in Indian SAT Villages 333

Resource Management 335
- The Role of Common Property Resources in Traditional Farming Systems 335
- Composite Watershed Management on Alfisols 335
- Enhancing Productivity in Integrated Crop-Livestock Farming Systems 337

Workshops, Conferences, and Seminars 337

Looking Ahead 339

Publications 340

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ECONOMICS

This Annual Report integrates for the first time work of the Economics Program in India and West Africa. Despite regional differences, ICRISAT's social science research in the two SAT regions shares many common features. It focuses on technology and policy assessment, behavioral studies, and resource management. Research in both regions also relies heavily on data collected in village-level studies.

The Indian village-level studies were thoroughly described in ICRISAT Annual Report 1982, pp. 313-320. In West Africa we carry out village-level studies in Upper Volta and Niger. Our work in Upper Volta began in 1980 and has concentrated on baseline studies of current production and marketing systems and on on-farm tests of technologies. Our activities involve nearly 150 participating farmers selected from 6 villages in the 3 major agroclimatic zones of Upper Volta: the Sahel, Sudanian Savanna, and northern Guinean Savanna. Crop production and transactions data were collected in 1983, with slightly modified versions of the 1982 questionnaires, in 100 farm households in 4 villages of western Niger.

Whereas farm size was the criterion for sample selection in India, respondent households in the Upper Volta study villages were randomly chosen after stratifying for ownership of animal traction. Anthropological studies became in July 1981 an important part of the West African economics program.

Technology and Policy Assessment

Farmers' Tests of Technology in Upper Volta

Upper Volta's 1983 rainfall continued substantially below average, with relative deficits most acute in the more southern (usually the more humid) regions. The national pattern was closely reflected in the study villages (Table 1).

Table 1. Rainfall in 6 study villages of Upper Volta; 1981, 1982, and 1983.

Region	Long-term average rainfall[1] (mm)	Village	1981		1982		1983	
			Total (mm)	% of long-term average	Total (mm)	% of long-term average	Total (mm)	% of long-term average
Djibo	567	Woure	449	79	382	67	473	83
		Silguey	509	90	347	61	449	79
Yako	756	Kolbila	707	93	586	78	650	86
		Ouonon	547	72	552	73	NA[2]	NA
Boromo	981	Koho	NA	NA	849	87	778	79
		Sayero	907	92	605	62	622	63

1. Source: A handbook on the rainfall climatology of West Africa: data for selected locations. ICRISAT 1980. Information Bulletin 7.
2. NA = not available.

Evaluation of Sorghum and Millet Varieties

As in earlier years, our technology evaluation emphasized farmer-managed tests of promising cereal varieties. Three sorghum varieties (82S 47, 82S 50, SPV 35) and three millet varieties (IKMV 8101, 8201, 8202) were tested in 1983 as alternatives to local varieties in moderate-to-late planting situations.

82S 47 and 82S 50 were each tested by 25 farmers in the Boromo study villages and by 12 in the Yako villages. SPV 35 was tested by 25 farmers in the Djibo villages. The three millet varieties were each planted by up to 8 farmers in both the Yako and Djibo zones. A split-block design was used for the test field of each farmer with varieties as the main blocks (test variety and local variety control) and 6 fertilizer rates as the subtreatments. Subtreatment plots for each variety were 150 m² for sorghum and 100 m² for millet. We systematically varied fertility rates from 0 to 400 kg 14:23:15/ha (see "Economics of Fertilizer Use"). Farmers served as replicates for the analysis.

Sorghum variety 82S 50 had better seedling emergence than local controls in both Boromo and Yako under all methods of soil preparation (direct seeding, hand scarification, and mechanical plowing). 82S 47 performed about the same as local varieties in seedling emergence, except in Boromo where it was significantly inferior under zero tillage. SPV 35 had significant establishment problems, particularly under zero tillage (29% empty hills compared with 14% for the local control). None of the varieties tested differed significantly from the local controls in seedling establishment.

Of the three white sorghum varieties, only SPV 35 showed poor adaptability—yields significantly less than local controls at all fertilizer levels. Except at Koho, the study village with the highest rainfall in 1983 (778 mm), 82S 50 outyielded local controls at all fertilizer rates, and with no fertilizer. 82S 50 was also more responsive to increasing fertilizer than either 82S 47 or local controls. Without fertilizer 82S 47 was consistently inferior to local varieties.

As in previous years, millet varieties tested produced disappointing yields at all fertility levels in both Djibo and Yako. Local varieties outyielded the test varieties 20 to 90% on fertilized plots, and 50 to 150% on nonfertilized plots.

In many cases, birds markedly reduced yields of test varieties, most severely in Djibo among the nonphotoperiod-sensitive millet varieties tested (more than 20% losses in more than 44% of the plots), and also in the early-planted partially photosensitive 82S 50 in Boromo (Table 2). Fertilized plots, with accelerated crop growth, consistently suffered the most bird damage. But bird damage never exceeded 20% in the later-maturing local varieties in any zone.

These results suggest that recommended dates of planting (the first 2 weeks of June for 82S 47 and 82S 50, and immediately after 5 July for IKMV 8101, 8201, and 8202) may be too early. To identify more suitable planting dates, we examined how yields varied with planting dates. The performance of 82S 50 was superior in the Yako zone for planting dates after 15 June in fertilized or nonfertilized plots. In Boromo, although there were no differences in response to planting date among the varieties not fertilized, marked differences were apparent in the fertilized plots, with 82S 50 superior for planting dates after 25 June.

Similar analyses were conducted for millet

Table 2. Yield losses[1] due to bird damage in tests on farmers' fields, Boromo, Upper Volta, 1983.

Variety	Fertilizer treatment (kg/ha)	Date planted 4-18 June	19 June-1 July	2 July-3 Aug
		% of plots where yield loss exceeded 20%		
82S 47	0	30	0	0
	100 NPK+ 50 urea	20	25	17
82S 50	0	29	28	0
	100 NPK+ 50 urea	43	29	0

[1] Determined by visually comparing grain yield from damaged plots with those from plots with no bird damage.

varieties, but only in the Yako zone because the Djibo test had such a limited range of planting dates. In all of Yako planting dates (4-18 July), our analysis showed that test millets yielded less than local varieties. Predicted yields, however, tended to increase for the test varieties planted later, and were superior to local varieties' with either fertilizer level.

Although farmers want earlier-maturing varieties of both sorghum and millet for late planting, our millet results clearly indicate that increased photosensitivity is necessary for flexibility in planting date. Before varieties are tested with farmers, additional date-of-planting trials, with and without fertilizer, are necessary to more accurately determine best planting dates.

Economics of Fertilizer Use

Farmers' tests of new varieties at 2 fertility rates in 1982 showed that, for local varieties of sorghum and millet in the Sahel and Sudanian zones, at subsidized fertilizer prices, returns on the recommended 100 kg/ha of cotton complex fertilizer (14:23:15) were generally low, though positive, but negative without the subsidy. We also observed that returns varied highly across sites, reflecting high risk of financial loss when complementary management and/or environmental conditions were absent.

Farmers' tests in 1983 were designed to verify those results and to answer the following questions:

- How do mean returns and risks of financial loss vary across a range of fertility levels?
- What fertilizer level maximizes farmer's short-term profits?
- What factors determine variability in technical response to fertilizer?
- What are the marginal returns and risks to 50 kg urea/ha added to the basal 100 kg/ha of cotton complex fertilizer?

Six fertility levels were used: (1) zero; (2) 50 kg f/ha (f = fertilizer at 14:23:15); (3) 100 kg f/ha; (4) 200 kg f/ha; (5) 400 kg f/ha; and (6) 100 kg f/ha + 50 kg urea/ha. All farmers carried out treatments 1,3, and 6, while treatments 2,4, and 5 constituted a 4th treatment randomized across farmers. To eliminate possible errors in the amounts and placement of fertilizer, ICRISAT personnel applied all fertilizer, while other operations (except harvest) were performed by the farmers.

Mean return estimates were calculated from yield increments at different fertility levels on the basis of paired observations within each site. Average and marginal rates of return to investing in fertilizer, calculated at subsidized fertilizer prices, indicate that:

- Returns on fertilizer were greater in the more humid southern zones, than in other zones tested, with the pattern most evident at low fertilizer rates. Returns were generally negative or noncompetitive in the Sahelian region across all fertility levels with sorghum or millet.
- In the Yako region, a transition zone between sorghum and millet cultivation, returns to fertilizer were consistently greater from sorghum than millet.
- Average rates of return declined at higher fertilizer rates in all zones, with the decline most rapid for millet and local varieties.
- Marginal returns were maximized at the lowest fertilizer rate in all cases, except for improved sorghum varieties in Yako where sorghum's response was highly profitable with up to 100 kg/ha of fertilizer.
- Adding 50 kg urea to the basal 100 kg NPK/ha was highly profitable for sorghum in both Yako and Boromo, but unprofitable for millet in Yako.

The 1983 results confirm the high financial risk associated with fertilizer use, particularly in the more arid Sahelian zone. The proportion of plots where increased yield failed to equal the cost of fertilizer exceeded 50% for most fertilizer rates in that zone, but was less than 40% in the two more humid zones. Moreover, risk of loss was generally least at the lowest fertilizer rate, 50 kg/ha.

We also examined the implications of removing the existing 42 to 46% fertilizer subsidies on average and marginal returns, as well as on financial risk for farmers. Without subsidies, incentives to use fertilizer would be significantly reduced in Boromo and Yako, and eliminated in Djibo. For local varieties in the Boromo and Yako zones, a 100% or greater return is achieved only at the lowest fertilizer rate, 50 kg/ha.

Moreover, the recommended package of 100 kg NPK/ha plus 50 kg urea/ha exceeds a 100% return criterion only for test sorghum varieties in the Yako and Boromo areas. Average returns were consistently negative at all fertilizer rates in the Djibo region. The marginal returns and risk analyses confirmed that without subsidized fertilizer prices, incentives to use fertilizer would exist principally for the lowest rates. Using official rather than market prices for cereals did not change the conclusions.

Considering shortages of farm capital, high variability in returns and financial risk, and the associated costs of fertilizer use (additional labor to purchase, transport, and apply fertilizer, and to control fertilizer-induced weed growth), low rates of cotton complex fertilizer (less than 100 kg/ha) are most appropriate for farmers' fields.

With limited fertilizer supplies, lower application rates would give a larger aggregate increase in production and highest returns on government subsidies. Adding urea to a basal dose of cotton complex fertilizer at currently recommended rates is not profitable in Djibo and it is profitable only for sorghum, not millet, in the Yako and Boromo zones. We have not examined other rates of urea in combination with cotton complex fertilizer.

Our conclusions are tentative because they are from a year of below-average rainfall, and relatively few observations, particularly at the extreme low and high fertilizer rates. We shall repeat the tests in 1984 with an increased number of observations.

Finally, our results do not consider whether the balance of nutrients in cotton complex fertilizer is economically optimal for sorghum and millet in the various zones, nor whether it would adversely affect soil quality. Both subjects urgently need complementary agronomic and economic research.

Effects of Contour Bunds on Grain Yields under Farmers' Management

The Voltaic government since the early 1970s has encouraged construction of dirt bunds in regions where continuous cultivation has exposed soils to increasing erosion.

During the 1982 and 1983 cropping seasons, the Fconomics Program collaborated with the Fonds de Development Rural (FDR), the Voltaic agency in charge of the bund program, to evaluate direct effects of bunds on sorghum and millet yields, and to identify interaction effects in order to determine what environmental conditions and complementary factors would maximize benefits from bunding.

Yield plots were systematically installed in five villages in 1982 and in seven villages in 1983, along the margins of bund systems in farmers' fields. Yield plots were placed to represent the upper, middle, and lower third of the area between adjacent bunds. Control plots were paired with each interior yield plot.

Data from the pooled-yield plots inside and outside the bund system were analyzed separately for 1982 and 1983 by regression analysis (Table 3). The principal conclusions are:

- Bunds have a highly significant positive impact on yields, with increases of 250 to 350 kg/ha.
- The impact of bunds goes up as slopes become steeper. Over the range of sites observed (where the average slope both years was 1%), a 1% increase in slope increased the yield attributable to bunds 310 kg/ha in 1982 and 160 kg/ha in 1983.
- Bunds and fertilizers may also interact positively. The hypothesized effect of dual impacts from improved soil-moisture storage and reduced runoff, however, was significant only in 1982.

Table 3. Effect of contour bunds on cereal yields, results from tests on farmers' fields in Upper Volta, 1982 and 1983.

Variable[1] (measurement)	1982	1983
Sorghum (0,1)	135.1	735.2**
	(1.40)[2]	(7.59)
Plowing (0,1)	33.7	-249.9*
	(0.41)	(-2.34)
Slope (0.02 degree)	1.2	-3.2*
	(0.52)	(-2.26)
Date planted	8.7**	1.0
	(3.29)	(0.45)
Fertilizer (0,1)	122.4	82.1
	(0.75)	(1.02)
Fertilizer preceding year (0,1)	-93.1	98.5
	(-0.68)	(1.58)
Bunds (0,1)	349.1*	260.0**
	(2.03)	(2.54)
Bunds × sorghum	63.6	67.3
	(0.55)	(0.76)
Bunds × slope	6.2*	3.2
	(2.21)	(1.71)
Bunds × fertilizer	231.5*	-49.3
	(2.03)	(-0.64)
F ratio	10.60	26.53
$\bar{R}^2$	.52	.68
Number of observations	153	214

1. Dummy variables for village locations, included in the model, are not shown. Significant location effects were present in only one village and only in 1982.
2. t-values are in parentheses.

Farmers' Tests in Niger

Farmers' tests, similar to those during the 1982 cropping season (ICRISAT Annual Report 1982, pp 367-368), were our principal activity in 1983. The tests were to examine management and environmental factors that affect millet yields.

Twenty-six farmers in the northern site, Sadeize Koira, and 28 in the southern site, Gobery, planted the tests in 1983. Rainfall in Sadeize Koira was 360 mm; in Gobery 392 mm. Millet yields in 1983 were generally higher than in 1982, especially in Sadeize Koira.

Of measured environmental yield-reducers including shibras millets, *Striga*, *Raghuva albunctipella*, stem borers, and downy mildew, only shibras millets significantly affected yield in Sadeize Koira. Differences in soil characteristics were much more important than differences in insect and disease incidence in Gobery. Organic matter, soluble phosphorus, and loam content significantly increased yields.

Fertilizer increased yields ($P<.01$) of both the local variety and the improved cultivar in both Sadeize Koira and Gobery. But neither cultivar had a significant interaction with either site or fertilizer. Despite a dry year and low average experimental yields of only 520 and 460 kg/ha in Sadeize Koira and Gober, respectively, it paid to apply fertilizer at both sites. In Sadeize Koira, fertilizer on improved cultivar HKP was profitable at official and market prices and in Gobery, with improved cultivar CIVT, it was even more profitable.

Whole-Farm Constraints to Adopting Improved Vertisol Technology

An improved Vertisol technology has been tested in farmers' fields in Taddanpally village, Andhra Pradesh, India, since 1981/82 (ICRISAT Annual Report 1982, pp. 309-313, and Ghodake 1983). To better understand the impact of that technology at the farm level and to identify more thoroughly which resources are needed most for adoption, we built a quadratic programming model for representative small, medium, and large farms in Taddanpally.

In the model, farmers were assumed to maximize expected income, which considers both the profitability and riskiness of present and prospective cropping activities, subject to resource availabilities and household consumption requirements. Potential resource constraints included rainfed and irrigated land, household male and female labor, bullock pairs, and cash available to finance agricultural production. Households could hire male and female labor, rent additional bullock pairs, and borrow from informal and institutional sources.

Salient features of the representative farms are presented in Table 4. The representative small farm relies completely on dryland agriculture,

Table 4. Characteristics of representative farms in Taddanpally.

Characteristic	Farm size Small	 Medium	 Large
Operated land (ha)	1.53	3.34	6.88
Irrigated land (ha)	0	0.54	1.62
Net irrigated land (%)	0	16.2	23.5
Male workers (No./10 ha of operated land)	11	6	4
Female workers (No./10 ha of operated land)	9	4	6.5
Bullocks (pairs/10 ha of operated land)	2.2	4.4	2.4
Owned cash (Rs/farm)[1]	0	200	500
Borrowing limit from institutional agencies (Rs/farm)[2]	1100	2300	4800
Borrowing potential from informal sources (Rs/farm)[3]	450	600	1000
Risk attitude (absolute risk aversion coefficient)[4]	0.001345	0.0009973	0.0004141
Farms represented (%)	51	33	16
Cultivated land represented (%)	21	40	39

1. An estimate of what the farmer saved the previous agricultural year for current-year farm production.
2. Refers to a short-term crop loan from an agricultural bank or village cooperative according to present scales of finance.
3. Informal sources include moneylenders, businessmen, relatives, and friends.
4. Derived from values of partial risk-aversion coefficients and distributional results obtained in experimental games.

while the representative large farm—about 400% bigger—has 25% of its land irrigated. Decision makers for the three types were assumed to be less averse to risk as farm size increased.

Whole-farm aspects of the improved Vertisol technology were evaluated in two steps. First, an optimal farm plan was obtained for each representative farm type by including only farmers' present cropping activities in the model, subject to existing household resources and sustenance-consumption needs. Second, cropping activities from the improved technology, which expand the production potential of the farm, were added to the model to generate a second optimal farm plan. Comparing results from the two plans gives an evaluation of performance with and without the improved technology.

As the improved Vertisol technology becomes available, the cropping pattern changes markedly, as shown in Table 5. But some land remains in farmers' present cropping systems. Irrigated paddy was not affected by the new technology. Limited female family labor on the medium-size farm restricted improved technology to some 53% of its area. Seasonal labor constraints were less binding on the large farm.

How well the improved Vertisol technology scores is shown in Table 6. Benefits are relatively more on the small farm. Draft efficiency of the wheeled-tool carrier permitted bullock power to decline moderately on all three farm types.

To assess how much lack of credit can limit adoption of the improved technology and to determine a desirable scale of finance, we varied credit availability. In each farm-size category, a minimum credit of Rs 700/ha was required to reap potential benefits of the improved technology. At Rs 700/ha, for example, an additional rupee of credit would earn the equivalent of 97%

interest on the small farm. Using the assumptions in Table 4, we estimated that an optimal scale of finance from institutional agencies to invest in the improved technology would be Rs 1200/ha for the representative small farm, Rs 940 for the medium, and Rs 980 for the large farm.

High demand for female labor may delay adoption of the improved technology by households with few females. In specifying the constraints, we assumed that a farmer can hire labor only from his village. From mid-June to mid-July medium-sized farms could justify wages as high as Rs 15-20/hr to attract female labor from outside the village (Table 7). Shadow prices for female labor far exceeding average rates also indicate that the improved technology will help female labor obtain higher wages.

Designing cropping systems that do not demand female labor during the three peak shortage periods could stimulate adoption of the technology. The first such period is in late June and early July when sowing, fertilizing, and first weeding of improved rainy-season crops clashes with transplanting rice. In mid-September harvesting and threshing rainy-season crops and land preparation for planting postrainy-season dryland crops under the improved technology clash with rice harvesting and threshing. The last peak period (mid-November) competes with intercultivation of postrainy-season crops.

Seasonal demands for male labor and draft power do not impinge on adoption of the improved technology. Shadow prices for bullock pairs and male labor are positive for only one fortnight on the large farm. For the medium

Table 5. Optimal land allocations (% of total cropped area) for representative farms with the improved Vertisol technology, compared with farmers' present practices.

	Small farm		Medium farm		Large farm	
Cropping activity	Farmers' present practices	Improved Vertisol technology	Farmers' present practices	Improved Vertisol technology	Farmers' present practices	Improved Vertisol technology
Present cropping systems	100.0	10.0	100.0	47.3	100.0	29.0
Irrigated paddy	0.0	0.0	19.2	19.2	14.6	14.6
Fallow+local sorghum	20.9	0.0	39.4	11.6	35.8	0.0
Fallow+local sorghum or safflower	30.9	3.9	14.5	12.7	17.4	13.1
Fallow+local sorghum or pigeonpea	31.8	0.0	22.4	3.8	20.8	1.2
Green+sorghum	9.2	6.1	0.0	0.0	8.4	0.0
Improved Vertisol cropping systems		90.0		52.7		71.0
HYV sorghum/pigeonpea intercrop		50.1		23.8		22.8
Greengram+local sorghum		19.5		5.8		19.9
Greengram+chillies		1.0		0.0		0.2
Greengram+safflower		3.5		0.0		0.6
Greengram+local sorghum or chickpea		8.8		12.8		7.7
Maize/pigeonpea		0.3		5.4		12.5
Maize+chickpea		6.8		4.8		7.4

+ = sequential crop; / = intercrop. HYV = High yielding variety.

Table 6. Impact of the improved Vertisol technology (% change from present practices) on representative small, medium, and large farms.

Characteristic	Farm size Small	Medium	Large
Land-use intensity[1]	23	18	22
Gross income (Rs)	90	71	67
Variable cost[2] (Rs)	110	80	72
Net income (Rs)	85	68	65
Employment			
Male (hr)	26	19	17
Female (hr)	18	9	12
Bullock (pair hr)	-15	-5	-13
Borrowing[3] (Rs)	16	63	47
Cost of fertilizer (Rs)	1824	224	298

1. Land-use intensity is obtained by adding monthly cropping intensities over 12 months and dividing the sum by total land available for cultivation.
2. Variable expenditure includes imputed and out-of-pocket costs of seed and farmyard manure, fertilizer, and hiring bullock pairs, labor, machinery, and other inputs.
3. Borrowing includes both institutional and informal sources.

and small farms, negative shadow prices indicate that bullock pairs and male labor are plentiful throughout the cropping season.

Likewise, risk aversion does not adversely affect adoption of the improved technology, as that technology does not significantly increase risk over farmers' present practices. This finding is preliminary; additional verification over time is needed to assess the potential conflict between risk and expected profitability.

Technological Change in Indian SAT Agricultural Markets

The impact of technological change on agricultural markets in the SAT of India and Africa depends on interactions among commodities, not on individual crops, because diversified commodity production is the norm. Demand and supply responsiveness conditions consequences, especially where local markets are not integrated into larger markets, which is often the case in poorer areas. For example, some analysts have suggested that increasing sorghum productivity would depress prices so much that farmers would shift away from sorghum and the net gain in output would be small.

To investigate such interdependencies, we developed a nonstochastic simulation model based on demand-and-supply relations for 6 commodity groups: superior cereals (wheat and rice), sorghum, other coarse cereals, pulses, oilseeds, and other crops; and for two inputs: fertilizer and labor. Additional variables, such as rainfall, density of roads, and irrigation, which

Table 7. Shadow prices (Rs/hr) of female labor constraints with farmers' practices and with the improved Vertisol technology for representative small, medium, and large farms.

		Small farm		Medium farm		Large farm	
Peak female labor constraints by fortnight	Mean wage	Farmers' present practices	Improved Vertisol technology	Farmers' present practices	Improved Vertisol technology	Farmers' present practices	Improved Vertisol technology
26 Mar-8 Apr	0.25	[1]	-	6.41	-	-	-
7 May-20 May	0.25	-	2.66	-	5.72	-	5.40
18 June-1 July	0.43	-	-	-	15.43	-	-
2-15 July	0.39	-	-	-	21.39	-	-
16-29 July	0.86	2.82	-	-	-	-	-
10-23 Sept	0.43	-	-	1.07	1.12	5.13	2.58
8-21 Oct	0.64	-	-	-	0.19	-	-
5-18 Nov	0.84	7.86	2.25	0.16	9.32	4.34	-

1. Female labor hired within the village not a binding constraint during indicated fortnight.

Table 8. Crop output supply elasticities for SAT India.

	Output supply elasticities					
	Superior cereals	Sorghum	Other coarse cereals	Pulses	Oilseeds	Other crops
Expected prices						
Superior Cereals	0.304	0.048	-0.247	0.107	-0.310	-0.096
Sorghum	0.020	0.431	-0.103	0.192	-0.087	-0.070
Other coarse Cereals	-0.081	-0.080	0.375	-0.348	0.100	0.081
Pulses	0.025	0.107	-0.247	0.872	0.016	-0.049
Oilseeds	-0.132	0.088	0.129	0.028	0.211	0.047
Other crops	-0.054	-0.092	0.139	-0.118	0.062	0.162
Other variables						
Rainfall	0.320	0.200	-0.087	0.257	0.072	0.158
Road density	0.179	0.041	0.081	-0.189	-0.676	0.747
Irrigation	0.321	-0.029	0.174	0.097	0.300	0.223

Source: Normalized quadratic profit-function estimates evaluated at sample means for expected prices from Table 5 and for other variables from Table 6 *in* Bapna, S.L., Binswanger, H.P., and Quizon, J.B. 1981. Systems of output-supply and factor-demand equations for semi-arid tropical India. Unpublished mimeo, World Bank, Washington, DC, USA.

influence supply, also figured in the model (Economics Program Progress Report 39, and Murty and Lalitha 1983).

The output-supply and input-demand estimates were taken from Bapna, Binswanger, and Quizon who used a systems approach based on district-level data from 13 SAT regions in Andhra Pradesh, Karnataka, Madhya Pradesh, and Tamil Nadu. Their estimated elasticities relevant for our simulations are summarized in Table 8. The elasticities imply some interesting partial-equilibrium patterns. The own-price elasticities range from 0.16 to 0.87, indicating fairly substantial price responsiveness in this relatively poor agricultural region. Several of the cross-crop elasticities are fairly large (with absolute magnitudes of 0.2 to 0.3), which suggests important intrasystem substitutions in production.

Increased rainfall augments production of pulses and superior cereals. Improvements in highway infrastructure cause a shift from oilseeds and pulses to superior cereals and other crops. Increased irrigation induces expansion of superior cereals and oilseeds, with no significant impact on other crops.

Estimates for total expenditure and price elasticities of demand are taken from Murty and Radhakrishna, who applied a generalized linear expenditure system to all-India household data collected by the National Sample Survey Organization. All of the own-price elasticities are negative, as theory suggests should be true for normal goods (Table 9). There are some fairly large cross-price effects, both positive and negative, primarily involving superior cereals. All expenditure elasticities are positive, with coarse cereals (0.69) less responsive than the other commodity groups to changes in expenditure.

In the model, past prices and infrastructural variables determine current supply, which in turn—together with observed current prices—generates income. With current commodity supplies and income, one determines within-period prices.

Because sorghum, other cereals, and pulses may not be well integrated with other markets, we structured the model so prices for them are determined within the SAT region. For superior cereals, other commodities, and fertilizer, we assumed that prices are determined outside the SAT. Oilseeds are an intermediate case, with

Table 9. Commodity demand elasticities for rural households in India's SAT.

	Demand elasticity					
	Superior cereals	Sorghum	Other cereals	Pulses	Edible oils	Other commodities
With reference to price of:						
Superior cereals	-1.204	0.829	0.563	-0.193	-0.331	-0.165
Sorghum	0.204	-1.917	0.151	-0.045	-0.077	-0.039
Other coarse cereals	0.188	0.205	-1.315	-0.084	-0.144	-0.072
Pulses	-0.011	-0.012	-0.008	-0.920	-0.042	0.003
Edible oils	-0.024	-0.027	-0.018	-0.035	-0.619	-0.001
Other commodities	-0.081	-0.088	-0.060	0.032	0.005	-0.879
With reference to total expenditure	0.928	1.010	0.687	1.240	1.123	1.153

Source: Nasse expenditure system estimates evaluated at sample means, for the second lowest rural expenditure group, in work summarized *in* Murty, K.N., and Radhakrishna, R. 1982. Agricultural prices, income, distribution, and demand patterns in a low-income country. Pages 155-173 *in* Computer Applications for Food Production and Agricultural Engineering (eds K.E. Kalman and J. Martinez). Amsterdam: North Holland and Publishing Company.

both SAT and non-SAT regions influencing their price.

Farming in the SAT differs considerably from more commercialized agriculture in that much SAT production is consumed by farmers themselves. This implies a connection between supply and demand additional to those established through market prices. To capture this link between household production and consumption, we explicitly assumed that total expenditure depends considerably on producer revenues.

The reference point for the scenarios is a base simulation in which all endogenous variables are solution values, given the values of exogenous variables and given also that all stochastic terms have expected values of zero. The base simulation starts in 1969 and runs for 10 years. A decade as the simulation period is adequate for the dynamic effects of initial exogenous changes to work their way through the system.

Simulated, rather than actual, values of lagged endogenous variables are used. The lagged simulated values are one of the two major mechanisms that link impact of hypothetical exogenous changes across years in a dynamic fashion. Results in one year are also related to those in another through an endogenous expected-price generating equation.

Goodness-of-fit statistics for the entire decade suggest that the model traces the actual experience for quantities supplied better than it does for prices, which is an expected outcome, assuming that within a period supplies are completely price inelastic, so all of the adjustments to short-run equilibrium must be in prices along the demand curve to the recursively set quantities supplied. The model quite well identifies turning points in agricultural experience over the simulation decade in India's SAT.

We used the simulation model to investigate several scenarios, including the impact of reduced rainfall, a 10% increase in noncrop SAT income, an increase in sorghum inventories held by the public sector equal to 10% of production, a sustained upward shift in road density or market access, and a 10% sustained increase in irrigated area. The most directly relevant scenarios for agricultural research institutions like ICRISAT are those that relate to increases in crop productivity. In one scenario, for instance, we assumed that sorghum productivity increases along a typical s-shaped pattern of adoption, with the growth rate reaching a maximum increase of 5% in the 5th year (1974) and declining thereafter.

The induced percentage deviations from the base simulation paths for 1971, 1974, and 1978 under this scenario are presented in Table 10. As expected, the price of sorghum falls to accommodate increased sorghum production within the Indian SAT region. By the 10th year the price declines 12.7%. Sorghum production does not increase as much as it would without an induced sorghum price movement. But sorghum output rises faster than the assumed increase in productivity. In the 10th year output is 33.1% above the base simulation path, even though productivity is only 25% above the path. Thus the fear that production gains from higher yields might be small because farmers would plant less land to sorghum appears to be unwarranted.

Even though the systemic effects are relatively weak for sorghum (in the sense that the cross-price elasticities in Tables 8 and 9 are small), there are small impacts on other commodities after several years. The lower sorghum price, for example, causes pulses to substitute somewhat for sorghum, oilseeds, and other crops and sorghum substitutes somewhat for superior cereals and other crops in consumption. Such cross effects lowered net imports of superior cereals into the SAT region and increased net imports and prices of edible oils. None of these effects is large. Judging by the cross-elasticity estimates in Tables 8 and 9, the systemic effects would be relatively greater for productivity changes in superior cereals.

Table 10. Effects of induced changes in sorghum productivity (1 to 5 to 1%, over 10 years) on Indian SAT crop markets.

Endogenous variable	Deviation from the base simulation by year, %		
	1971	1974	1978
Output supplies			
Superior cereals	0.1	0.0	-0.0
Sorghum	7.6	26.3	33.1
Other coarse cereals	-0.4	-0.9	-1.0
Pulses	0.7	22.1	2.1
Oilseeds	-0.4	-0.7	-0.6
Other crops	-0.3	-0.6	-0.6
Prices			
Sorghum	-3.4	-10.1	-12.7
Other coarse cereals	-0.0	-0.3	-0.7
Pulses	-0.3	-0.3	-0.5
Oilseeds - edible oils	0.6	1.8	1.7
Demand quantities			
Superior cereals	-0.6	-2.0	-2.5
Sorghum	7.6	26.3	33.1
Other items	-0.1	-0.3	-0.1
Expenditure	0.2	0.7	0.5

Behavioral Studies

Determinants of Individual Diets and Nutritional Status in 6 Indian SAT Villages

During 1976-78 we carried out a diet, health, and nutrition study in collaboration with the National Institute of Nutrition and the College of Home Science, Andhra Pradesh Agricultural University, in two regions of Maharashtra and two regions of Andhra Pradesh (a full-length report on this study will be published as ICRISAT Research Bulletin 7 in 1984). The aim was to determine the limiting nutrients in diets and factors that influence nutrient intake.

Our collaborators collected data on individual food intakes of 1200 people—from 240 households in 6 ICRISAT study villages—over 4 points in time. They used graduated aluminium cups for measurements and 24-hour recalls. Doctors measured height, weight, arm circumference, and triceps skinfold thickness in the surveyed households to help determine their nutritional status. The doctors also looked for clinical deficiency symptoms, and we recorded data for a smaller sample on how individuals spent their time during the day.

The major nutrient deficiencies observed were energy, calcium, β-carotene, B-complex vitamins, and ascorbic acid. Proteins and essential amino acids were not generally limiting, except

Nutrition study in progress: the collaborative study in southern India observed major nutrient deficiencies in energy, calcium, β-carotene, B-complex vitamins, and ascorbic acid. Proteins and amino acids were not generally limiting.

in particular circumstances, confirming a finding now increasingly common in nutrition studies. This supports earlier findings that ICRISAT can make a major contribution to improving nutrition in India by focusing on increasing yields and maintaining yield stability of its mandate crops. Substantial efforts to improve protein content and protein quality do not seem to be necessary, especially if that would lower yield or reduce stability.

The vitamin and mineral deficiencies suggest that production be increased of vegetables, dairy products, and fruits, which contain significant quantities of the lacking nutrients. Such increased production should tend to lower relative prices and thus also enhance real incomes of villagers. As income elasticities of demand for such 'protective' foods seem high, significant increases in consumption of vitamins and minerals could result. Nutrition education programs could further help this process. The energy deficit should be overcome largely by increasing availability of food grains, especially cereals. The study results do not support the idea that increased production of fruits, vegetables, and milk will be detrimental to the poor in developing countries.

Villagers in Maharashtra consume more sorghum and millet, while those in Andhra Pradesh rely more on rice. As a result, the Maharashtra villagers have higher intake of vitamins and minerals. Sorghum and millet contributed 12% of the calcium, 27% of the β-carotene, and 21% of the riboflavin in the diets of children 1-12 years old in the two Andhra Pradesh villages; the corresponding figures in the four Maharashtra villages were 24, 26 and 71%. If improved Indian cultivars of sorghum vary genetically in vitamin and mineral content, their nutritional status might be improved by screening for those traits. But further research would be desirable before actively incorporating vitamin and mineral screening in breeding programs. While nutrient status might be somewhat improved with such an approach, vitamin and mineral deficiencies in diets will still remain. The most effective strategy, at least at present, is to increase production and consumption of foods whose limited intakes are the major cause of identified nutrient deficiencies in SAT diets.

Except for calcium, which is derived mainly from milk and dairy products, individual nutrient intakes of children 1-12 years old were not influenced by r. . household income, after allowing for other variables. The reason this result diverges from that of most previous studies probably stems from how income is defined. We used a net income concept, while others have used expenditure or gross income as the explanatory variable. If our result applies to the rest of the Indian SAT, relying on income growth from economic development to alleviate nutritional deficiencies may not be sufficient.

Absolute and relative nutritional status as measured by both anthropometric analysis and dietary intakes depended mostly on the agroclimatic and socioeconomic characteristics of the areas involved. For example, villages with a cash crop like cotton as the major enterprise generally were better off nutritionally than those where rice and other food grains were dominant crops. Nutrition programs in SAT regions probably should focus on entire villages rather than on particular socioeconomic groups within them, except for households with the following characteristics:

- larger families, other things being equal, as child nutritional intakes, except for vitamin A, were generally lower in such families;
- landless and small-farm households, whose children's diets tended to be nutritionally less adequate;
- households where mothers have no formal education, because children of educated mothers got more vitamin A and calcium; but their consumption does not seem to increase as children age, so special programs for all households may be necessary to ensure that vitamin A and calcium intakes increase as children grow older.

Contrary to many other studies, we found no significant seasonal variation in anthropometric indices or in nutrient intake, except for B-complex vitamins, whose consumption generally increased during food-grain surpluses. Surpluses in the six study villages were mostly in the dry season.

The notion that malnutrition and morbidity are greatest in the wet season was not true in these villages. Even though food-grain availability may be greater in the surplus (dry) seasons, the availability of such 'protective' foods as leafy vegetables is much more restricted then than in the wet season.

As vitamins and minerals are a major dietary deficiency in these SAT villages, directing nutrition programs to the wet season may address only half the problem. Much more research is required on enhancing the availability of vitamins and minerals, especially in the dry season. Further development of such common property as village forests and wastelands, could play an enhancing role. The advantage of providing foods high in vitamins and minerals from common property resources is that poor people would benefit most. Further research is required to quantify precisely the seasonal availability of nutrients derived from village common property resources in the SAT.

Our study does not support the inference that improved technologies should not exaggerate labor peaks in the wet season for fear of adversely affecting energy balances. To advocate appropriate mechanization, use of chemical weed control, and high-yielding varieties, which are less time constrained in the wet seasons when the energy balance is apparently negative, ignores two basic factors.

First, creation of labor peaks is one of the few avenues whereby laborers can expect to increase their wage rates and employment. The landless and small-farm families, who rely most on wage labor for their sustenance, benefit most from labor peaks. Labor-saving technologies make their economic position worse. Second, in situations where soils have a high moisture-holding capacity, such as the Vertisols of large tracts of SAT India with undependable rainfall, typified by one of the Maharashtra regions in our study, much of the peak labor activity occurs in the dry season (when surplus food grain is most available), because crops are grown then on moisture stored in the soil.

In such agroclimatic environments and in highly irrigated villages, there is no necessary tradeoff between additional work activity in the peak labor periods and energy balance. The problem emerges mainly in Alfisol areas with low moisture-holding capacity and little irrigation, such as the Andhra Pradesh study regions, where crops are grown only in the wet season, when food-grain availability is low and labor demand is high.

The short periods spent on personal and child care, when adequate leisure time is available, suggest that child care, personal care, and hygiene are not considered important—a discouraging finding. If severe malnutrition stems less from food deficiencies than from inadequate water, poor sanitation, and infection, then the time spent in the home on personal and child care should be a key element in improving child nutrition.

Consumption and Nutritional Patterns of ICRISAT Mandate Crops in India

The equity and nutritional consequences of technological change are conditioned by consumption behavior and nutritional status. To learn more about these aspects, we estimated expenditure, price, and nutrient elasticities for 10 expenditure classes—5 urban and 5 rural—and 9 commodity groups, using pooled time-series, cross-sectional data published by the National Sample Survey Organization (Economics Program Progress Report 53, and Murty and von Oppen 1983).

Sorghum, pearl millet, and chickpea—all ICRISAT mandate crops—were included separately in the 9 commodity groups. The parameters were estimated within a complete demand-systems framework. Separate nutrient demand functions were not estimated, instead commodity demand was converted into nutrient demand through nutrient-content coefficients for energy and protein. Those estimates provide the raw material for food policy analysis for the ICRISAT mandate crops.

The average budget shares for the 5 rural and 5 urban expenditure classes and the 9 commodity groups are presented in Figure 1. Sorghum consumption accounts for about 8% of total expenditure by poorer families in both rural and urban areas. The relative allocation of pearl millet, like sorghum, is highest in the poorest households. Pulses, including pigeonpea and chickpea, constitute 3 to 4% of the expenditure for both rural and urban households. There is no marked difference in pulses' average shares of consumption across per capita expenditure level or income categories, or between rural and urban households. Groundnut's share in total consumption, together with other edible oils, varies from 3 to 5%.

Estimated mean expenditure and own-price elasticities follow patterns similar to the average budget shares. Expenditure elasticities close to unity for several cereal commodity groups for lower-income consumers indicate widespread poverty in these classes. As expected, the estimates decrease as income rises.

Commodities like sorghum, pearl millet, and other coarse cereals that are traditionally treated as inferior grains (i.e., commodities with negative expenditure elasticities), have quite 'high' estimates, close to and exceeding unity in a few cases. Clearly, aggregating income into only one group conceals disparities and blurs the distributional pattern of consumption expenditure.

The direct-price elasticities are more variable and volatile than are expenditure elasticities. Most of the direct-price elasticities are numerically large, indicating substantial price responsiveness in consumption. Consumers do react differentially to changes in relative prices according to their income levels. Unlike the aver-

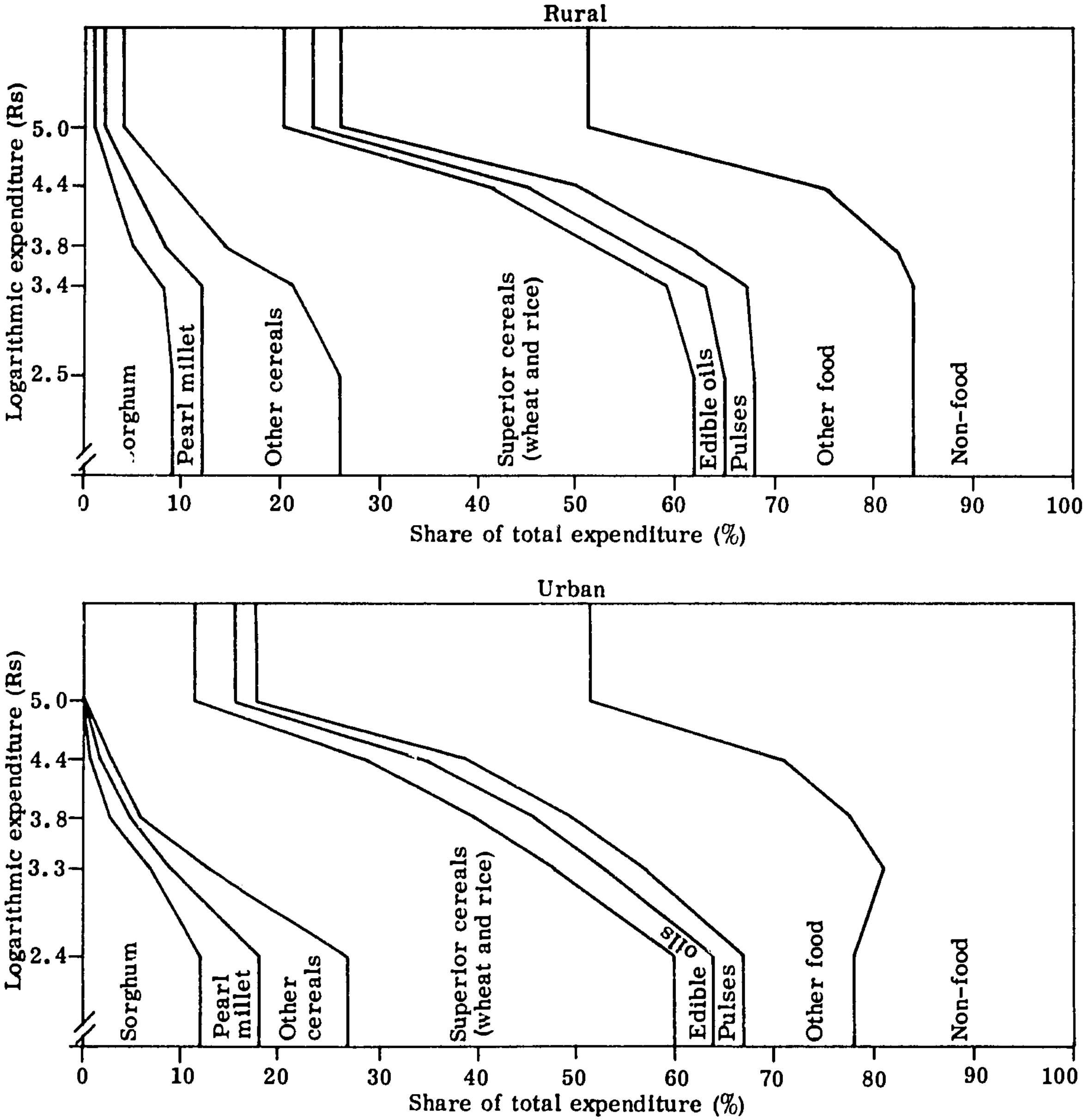

Figure 1. Average budget shares in total expenditure on commodity groups for rural and urban consumers.

age budget shares and expenditure elasticities, the direct-price elasticities do not display systematic patterns over income. In general they decline absolutely with rises in income for all foodstuffs; while the opposite is true for the nonfood group.

The large estimated cross-price elasticities indicate complementarity and substitutability across commodity groups. About 30% of the cross-price elasticities have absolute values greater than 0.05. In the rural lowest-expenditure group, superior cereals, sorghum, pearl millet, other cereals, and chickpea are gross substitutes for one another, while they are gross complements to edible oil, other pulses, other food, and nonfood commodities. For example, a 10% increase in the price of superior cereals (rice and wheat) would increase the demand for sorghum by 9%, pearl millet 8%, other cereals 5%, and chickpea 4%, which will collectively compensate for a 14% decrease in the consumption of superior cereals. Moreover, such a price hike would reduce the demand for edible oil by 1.9%, other pulses 2.3%, and other food 1.5%.

As we move from the rural lowest-expenditure group to the highest, the degree of substitutability of sorghum for rice and wheat declines about 36%; that is, the cross-price elasticity of sorghum with reference to superior cereals price declines from 0.94 to 0.60. Similarly, the substitutability of pearl millet for sorghum decreases 84% (from 0.26 to 0.04).

Converting commodities into nutrients, we find that sorghum and pearl millet supply about 15 and 5% of the energy intake for the poorest rural and urban households (Fig. 2). For sorghum this percentage declines markedly with increasing expenditure for both rural and urban households; for pearl millet the same share is relatively constant in rural households across expenditure classes. Sorghum is also an important source of protein, particularly for the lowest expenditure groups. Pulses, including chickpea, and other foods contribute much more, absolutely and relatively, to the protein intake of the richer rural and urban households (Fig. 3).

Table 11. Calorie intake elasticities with reference to commodity prices.

Expenditure class	% population	Commodity price group			
		Superior cereals[1]	Sorghum	Pearl millet	Other food
Rural India					
1	6.72	-0.35	-0.17	-0.07	-0.10
2	16.89	-0.43	-0.14	-0.09	-0.11
3	39.53	-0.35	-0.06	-0.04	-0.14
4	29.80	-0.25	0.02	-0.03	-0.15
5	7.06	-0.16	-0.02	-0.02	-0.16
Urban India					
1	0.91	-0.50	-0.11	-0.01	-0.19
2	11.30	-0.44	-0.09	-0.06	-0.16
3	34.47	-0.32	-0.03	-0.02	-0.18
4	37.13	-0.18	-0.02	-0.01	-0.23
5	16.19	-0.10	0.00	0.00	0.00

1. Include wheat and rice.

Technological change that drives down the price of superior cereals and consumer-price subsidies on rice and wheat would be the most effective way to improve calorie consumption by the poorest rural and urban households. For them, a 10% decrease in the price of superior cereals would stimulate a 3.5% and a 5.0% increase in caloric intake (Table 11). Price subsidies on, or technological change in, sorghum and pearl millet would not be so effective.

The same finding applies to protein intake. Protein intake by all consumer groups is much more responsive to changes in cereal prices than to equivalent changes in pulse prices. Price subsidies on pulses would, therefore, be inappropriate as a policy to promote protein consumption. Although pulses are a cheaper source of protein than cereals, price subsidies on cereals are from 250 to 400% more effective in augmenting protein intake by the poorest two expenditure groups in both rural and urban areas than are proportionally equivalent subsidies on pulses. This result underscores the strength of intercommodity substitution effects in conditioning nutritional consequences and amply illustrates that simple, least-cost criteria that ignore commodity interdependencies and rely solely on maximizing nutrients per unit of expenditure can give misguided advice on nutrition-price policy.

These conclusions are based on estimates from all-India data. Regional data could well produce a different set of estimates, with different implications.

Describing Production and Marketing Patterns in Upper Volta

Since 1981, we have intensively surveyed a panel of Voltaic farmers in 6 study villages, collecting information on production, marketing, and consumption. These early analyses were aimed at characterizing the major patterns of production and market involvement.

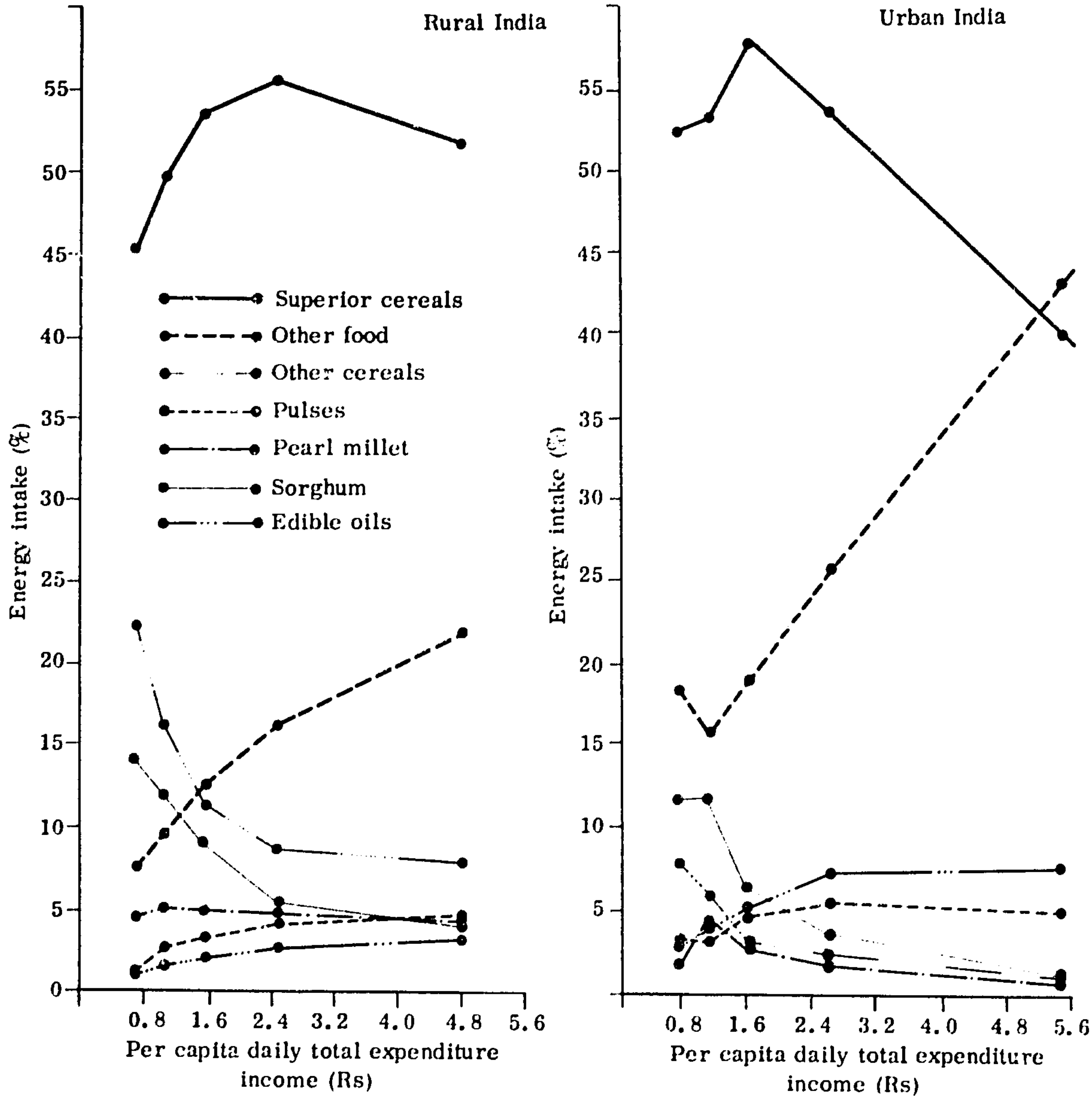

Figure 2. Energy intake by source and income level.

Productivity and market dependence vary widely between years. Due to substantial decline in rainfall between 1981 and 1982, yields of millet, the principal cereal in the Djibo zone, declined nearly 60%; in Yako, yields for the principal cereal there, white sorghum (and millet), declined nearly 50%; and in the Boromo region yields for the principal cereals, white sorghum, maize, and red sorghum, declined approximately 10%, 30%, and 50%, respectively.

In 1982 production could not meet even subsistence needs of nearly all groups. These results are most surprising, perhaps, for Boromo farmers located in the northern Guinean savanna zone, but can be explained in part by the role of cotton—30% of cultivated area—in the farming systems of that region. Data from a small cohort of adult men and women weighed 5 times between May 1982 and September 1983 also suggest that the 1982 crop failure probably

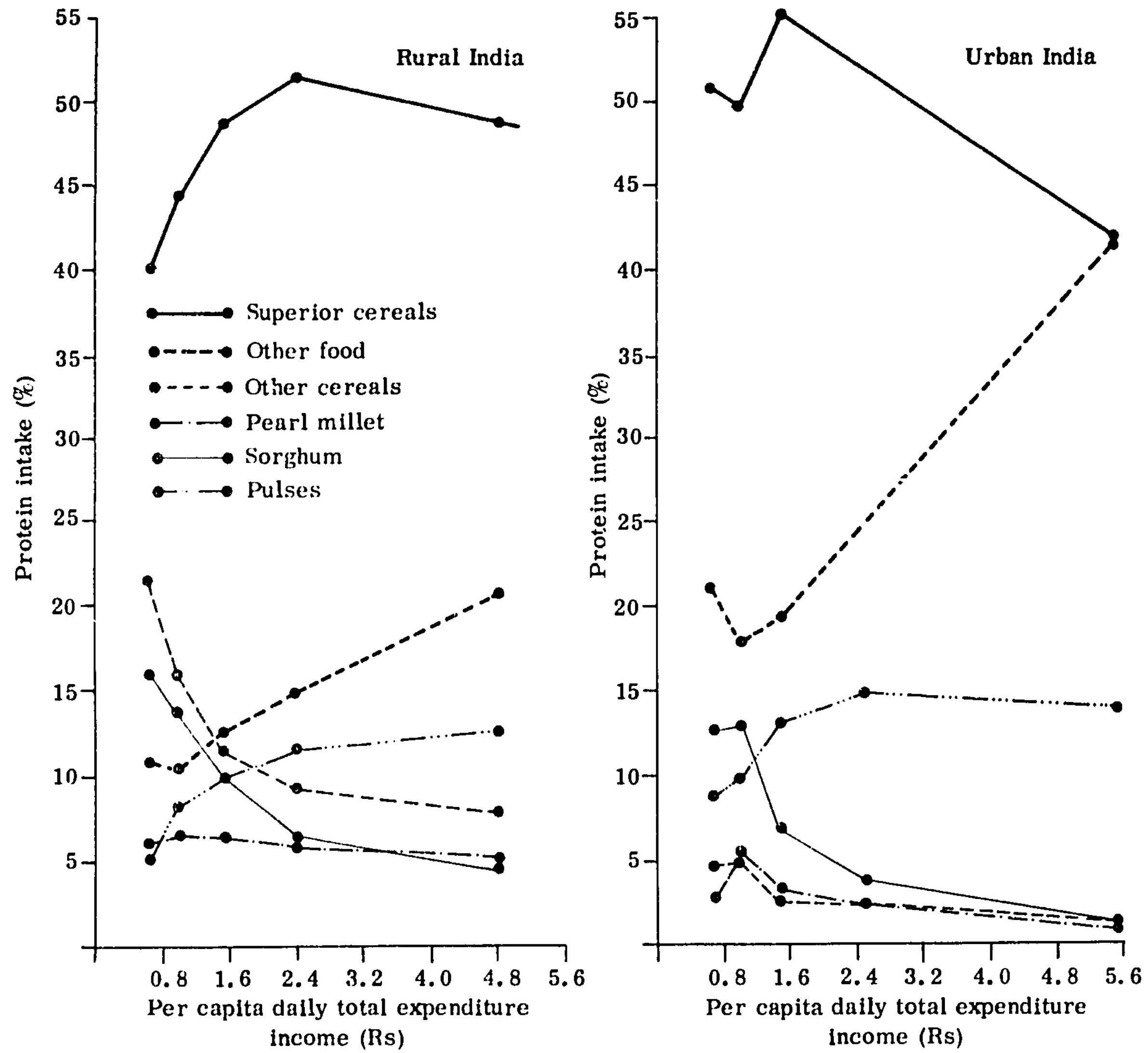

Figure 3. Protein intake by source and income level.

accounts for the lower weights observed in all the zones.

Even in 1981, a year of generally adequate rainfall, farmers in the Yako and Djibo zones on average bought more grain than they sold, reflecting aggregate net deficits in both regions. Purchases in these two zones in 1981 were approximately 5% of total grain available. In contrast, Boromo farmers in 1981 balanced purchases and sales, with cereal exchanges representing principally trade for preferred grains and for red sorghum used in beer making. By 1982, however, purchased grains provided 40% of available cereals in Djibo, approximately 15% in Yako, and between 7 and 35% in the two Boromo villages.

Assessing Socioeconomic Change in Upper Volta

Population growth and continuing drought are two major factors in changing the farming systems prevailing in the West African SAT. In 1982, ICRISAT's census of the six study villages in Upper Volta showed a net increase in population of more than 14% since 1975. Data presented in Table 1 of this report indicate that all villages experienced rainfall below the long-term average (maximum shortfall 40%).

Recurrent prolonged droughts are not new to the region. Climatological reports published in 1982 documented the persistence of the sub-Saharan drought since 1968. It has been suggested that a drought-induced decline in human and animal populations in the early 1970s reduced the impact of low rainfall in later years. In the ICRISAT study villages, increasing population in all agroclimatic zones seems to contradict that suggestion. In a postharvest survey of three villages, outmigration during the past 10 years was lowest (4% of the adult population) in the Sahel village, compared with 28% in the Sudanian zone village and 34% in the northern Guinean zone village. Outmigration, both permanent and seasonal, represents one possible response to population increase and continuing drought.

Farmers are also resorting to other mechanisms to cope with the double stress of increased population pressure and drought. The farming system is being changed in the following ways:

- Early-maturing varieties of major food crops are being adopted.
- The area under cultivation is being expanded; since the better land is already occupied in most regions, such expansion involves exploitation of more marginal lands.
- Agriculture is becoming more intensified in all zones. More manure and fertilizer are applied to bush fields, plows and carts are used increasingly, and the fallow period is being shortened.
- Land-tenure systems are changing from communal 'use rights' to a more permanent 'farm tenure', involving inheritance from father to son.

These changes are interlinked. The adoption of earlier maturing varieties is partly an adaption to the low rainfall, and partly a response to the movement to more drought-prone marginal lands. The adoption of plows and carts enables cultivation of fields more distant from the homestead. With shorter fallow periods, the fertility of the soil must be replenished with manure and fertilizer. More permanent cultivation leads to more permanent forms of land tenure.

ICRISAT scientists are interested in exploring the consequences of this intensification, especially the potential benefits from increasing use of manure and animal traction. Paradoxically, greater population density tends to cause a breakdown in herder-farmer relations when greater integration between livestock and crop production is needed. Cattle production traditionally is separated from crop production, with each activity carried on by a separate ethnic group. With more permanent and expanded cultivation, less pasture is available to herders. Conflicts increase over crop damage by cattle.

Meanwhile, shorter fallow periods can impoverish the soil. Manure becomes more valuable to crop production. Traditionally, herders are entitled to the milk and manure of the animals they are herding, even if the animals are not their own. In the Guinean zone where most herders look after the farmers' cattle, a market for manure is developing. In the more densely populated regions (Sudanian zone), many herders have migrated away from the villages owing to lack of pasture. The remaining herders themselves are becoming more dependent on crop production and thus keep the manure for use on their own farms. Other farmers in the area must rely more and more on chemical fertilizers.

Some traditional ways of coping with low rainfall are becoming less common. For instance, long-term grain stores are giving way to reliance on purchasing imported grain. In parts of Ivory Coast, Mali, and Senegal, grain stores of 4 or more years were apparently common in precolonial times, and farmers in southern Mali still grow white sorghum as a security stock and expect it to keep for up to 10 years. In 1982, 40% of farmers in a study village (Kolbila) reported that they had some grain in store from 3 previous harvests, 46% had some grain from 2 previous years in store, and 14% claimed to have

A woman in Kolbila village, Mossi plateau, Upper Volta, grinding millet for the evening meal, indicating a preference for ground over pounded cereal. ICRISAT's socioeconomic research includes behavioral studies of farm families.

grain from 5 or more years in storage. After the 1982 crop failed, a follow-up survey of grain stores in 1983 revealed very few farmers in that village who had grain reserves from more than 1 year. In the southern zone, stores of grain from 2 to 3 previous years were common in the more traditional village, Sayero, but were depleted in the more commercialized village, Koho.

With the decline in long-term security stocks, West African farmers are becoming more vulnerable as the drought continues. This may be true especially of those who have opted to rely more on purchases of imported grain.

Variations in Productivity among Upper Voltaic Farmers

Family size and composition influence farm productivity. The more dependents a farmer has, the more effort he puts forth. Sometimes called 'Chayanov's Rule,' this relationship between family composition (ratio of dependent to active family members) and agricultural productivity is conventionally measured by area cultivated and by cereal produced per worker. As the dependency ratio rises, so should these two parameters. Data from three study villages show that Chayanov's Rule generally holds across all three agroclimatic zones (Table 12).

Households with a similar dependency ratio and using the same technology can vary widely in their crop production. Some of these variations are correlated to ethnic group. Even within the same village, such differences can be profound.

In Koho village, different ethnic groups follow different economic strategies. Commercially oriented agricultural production, such as cotton, is more important to the Bwa ethnic group. Each Bwa farmer working with hand tools produced nearly four times the cotton of comparable Dagara farmers, but only about half the cereal.

Table 12. Family composition and productivity in 3 ICRISAT study villages, Upper Volta.

Characteristic	Dependents: active family members 1.00-1.24	1.25-1.49	1.50-1.74	1.75-1.99	2.00+
No. of farms observed	9	19	19	13	6
Area per worker (ha)	0.77	0.99	1.03	1.56	1.30
Cereal per worker (kg)	156	197	259	385	248

The relationship between farm productivity and investment in equipment for animal traction is more complex. Over 50% of such equipment was bought in the last 3 years, and buyers were heads of productive households. Animal traction does not necessarily increase productivity. Rather, it indicates a preexisting tendency to invest in agriculture. But what causes this commitment to higher productivity in the first place? One important clue was that farmers who bought animal traction equipment usually also headed the household or homestead. Traditionally, it is the compound head (head of a multiple-family household) who has the authority over such family investments as livestock and capital equipment.

In Koho, the higher productivity of compound heads and their ability to invest in new technology could also result from their access to the accumulated savings of the extended family. These are most evident as cattle investments, which clearly account for the enormous differences in the volume of livestock bought and sold in Koho between the compound and the ordinary household heads. The head of the compound is usually the manager of these investments, which contribute to the financial security required to buy traction equipment and fertilizer, and to generate the grain surpluses that feed group labor and ensure that communal fields are promptly weeded and harvested.

For ordinary households, food production and purchases together do not always meet subsistence requirements. The higher cereal production of the compound leader probably compensates somewhat for such failures. When a smaller household suffers chronic shortages over a number of years because of illness or other misfortune, it can be 'carried' for some time by the more productive unit, pushing upward the effective cereal requirements the compound head must reckon with. This may help explain why compound heads sometimes buy large quantities of cereal despite their own cereal production manifestly exceeding their household requirements. In 1982, among the Dagara-djula of Koho, compound heads purchased an average of 144 kg per consumer, above their cereal production of 179.5 kg per consumer. This gives a total of 323.5 kg per consumer, far more than the 180-200 kg estimated to be the minimum required.

Having shown that variation in productivity can arise from differences in ethnic background and social organizational patterns, one may ask whether introducing animal traction has qualitatively affected household structure and mutual risk sharing.

An ICRISAT consultancy report warns that the introduction of such new technology as animal traction and greater commercialization can contribute to "the appearance of new and potentially greater inequalities founded not on social structure but on changes in the relationships of production" (ICRISAT Research Bulletin 4. v.1, p. 91). It can also lead to breakup of the traditional complex family unit (consisting of more than one married man plus dependents) into simple nuclear family units (one married man plus dependents). Earlier studies suggest that compound elders tend to lose authority over junior household heads with the introduction of new technology and credit schemes that are more readily adopted by the younger men.

In the study villages, adoption of animal-traction equipment seems to be happening within the traditional investment structure, as shown by the high correlation between possession of the equipment and status of the household head. This indicates that if a breakdown in the traditional social organization is occurring, it need not result from the adoption of new technology nor from the introduction of cash cropping.

It appears rather more likely that erosion of wealth, in the form of cattle and other investments, might play a role in such changes in social organization. In other tribal societies, where anthropological studies have been carried out during times of stress such as famine or continuing drought, a common response has been that the flow of mutual aid is pulled gradually inward to the nuclear family unit. As wealth and resources decline, each farmer hoards what resources he has for himself and his immediate dependents. With the return of better days, the circle of sharing expands again to include a larger body of kin, such as may be represented by the compound cluster.

Management Variation and its Determinants in India's SAT

What distinguishes a good farmer from a bad one? That intriguing question cuts across many disciplines. To address it, we evaluated managerial performance over time with respect to farmers in the same village (Walker, Singh, and Bhende 1983). We based our assessment of managerial performance on data over 5 cropping years (1975-76 to 1979-80) from ICRISAT village-level studies. The data pertain to a panel of 180 cultivator households, 30 in each of the 6 villages chosen to represent three broad soil, climatic, and cropping regions in the SAT of rural southern India.

Returns to management were estimated as a residual after the monetary and opportunity costs of all factors of production were subtracted from gross crop returns, which also included the marketed and imputed value of all crop outputs.

To estimate interfarm differences in management behavior within a village, we regressed returns to management for each cultivator household, using cropping year and farmer as binary variables. This specification is a linear, fixed-effects model and is equivalent to carrying out a simple analysis of variance for cropping year and farmer effects with a balanced design.

The regression results showed that only a few farmers performed significantly better or worse as managers than a representative farmer with the median return in each village; 7% had significantly higher returns to management than the representative farm household, and 3% had significantly lower returns. The remaining 90% had about the same level of returns.

Despite the absence of a statistically significant difference in the performance of the majority of farmers, the range in the estimated coefficients from the worst to the best performer in each village is fairly wide, particularly in the more heavily irrigated Dokur and rainfall-assured Kanzara where a productive resource base allows managerial potential to be expressed. For all villages, interfarm differences between the poorest and best manager have a more pronounced effect on returns to management than does intertemporal variability between the poorest and best cropping year.

Having quantified the variation in management performance within the village, we next evaluated the determinants of interhousehold differences by regressing the estimated individual-farmer effects on personal characteristics and resource-endowment features that are hypothesized to influence managerial performance. In the six predominantly dryland farming villages, farming experience in acquiring access to productive opportunities and in allocating resources efficiently was the overriding consideration separating good from bad managers. Older farmers, those born into traditional farming occupations, and those who practiced hands-on farming had significantly higher returns to management. Farmers with more education were significantly better managers in one region, where primary and secondary education have a longer history and are more developed than in the other two regions.

Because of the small sample size and possible errors in evaluating opportunity costs, our results must be viewed as only illustrative. They indicate that managerial performance can be significantly different within dryland farming villages, and that variation in personal characteristics and social stratification can partially explain such interfarm differences. If the illustrative results apply to other villages in the SAT of rural southern India, they imply that policies that could effectively generate nonfarm employment and hasten farm-to-nonfarm migration will have the additional benefit of increasing productivity of private agricultural land, if part-time farmers from traditionally nonfarming occupations are more responsive to migration incentives than are traditional full-time farmers.

Income Fluctuations in Indian SAT Villages

To evaluate technological and institutional means to stabilize household production, income, and consumption, it is necessary to quantify and understand the level and determinants of instability in the semi-arid tropics (Economics Program Progress Report 57). Initially, we examined household-income stability over 5 cropping years from 1975-76 to 1979-80 for 110 continuous sample households in 3 study villages where we have posted resident investigators since 1975.

Most households in the 3 villages are extremely poor. The median income of Rs 550 per person (averaged over 3 villages) converts into US $63 per person in 1977 prices, and is about one-half of the all-India per capita income estimate of Rs 1080 for 1977. More than 80% of the households had a per person income of less than Rs 1000.

The coefficient of variation of per person household income over the 5 cropping years ranged from 8 to 86%. The mean coefficient of variation was 35%, which implies a 20% shortfall in income in 1 year in 4, and a 50% drop in 1 year in 14. There was no marked difference in income fluctuations between poorer and richer households. The mean coefficient of variation was significantly greater in Aurepalle, where households have to rely largely on private means to adjust to risk, than in Shirapur and Kanzara, where public works programs are active and represent an employer of last resort.

About one household in four suffered a 50% deficit in income in one year from the median income level over the 5 years. These shortfalls were not usually caused by a single adverse event, but conditioned by several bad events occurring simultaneously. Low labor income, the source of deficit in income for 7 households, was caused by reduced labor market participation in that particular year, which in turn was attributable to specific individual risk factors such as accident or disease, or to life-cycle effects associated with changes in family size. For 16 households, the shortfall in income was largely from low crop income, conditioned primarily by covariate yield risk from several crops. Fluctuations in gross cropped area also contributed to unduly low crop income for several households.

In general, earnings in the casual labor market tended to be the most stable source of income. For 10 landless households in Shirapur, for example, wages accounted for 72% of income, but labor's variance share was only 29%.

Most households derived most of their income from labor earnings, crop income, or both. Stabilizing the major source of income does not lead to appreciably lower coefficients of variation for most households. Perfect stabilization of the main source reduces the mean coefficient of variation by 35% in Aurepalle, 24% in Shirapur, and 20% in Kanzara. Except for landless labor and small-farm households in Kanzara, perfect stabilization of the main source of income does not lead to mean farm-size class coefficients of variation that are less than 20%. These results suggest that simple stabilization policies—focusing only on a single or main source of income—would not provide significant benefits to the majority of SAT households and that it would be extremely difficult, if not impossible, to stabilize household income to a level where the coefficient of variation of per person income is below 20%.

Stabilizing the main source of income does, however, protect households from suffering abnormally large income fluctuations. It reduces by 90% the probability of incurring a 50% shortfall from the median level of income.

The relative income position of different households within the village was fairly stable across the 5 years, especially in rainfall-assured Kanzara where the correlation coefficient for income rankings between 1975-76 and 1979-80 was 0.53. About 9 and 12% of the households were persistently poor and rich, defined as belonging to the lowest and highest income quartile, respectively, in at least 4 of the 5 cropping years.

Distributional measures within the village suggested greater income inequality when calculated for individual years rather than for the 5-year average. The estimated Gini concentration ratio in Aurepalle was as high as 0.47 for one cropping year, while the estimate based on mean household per capita income for the 5 years was only 0.35.

We also analyzed the effectiveness of farmer diversification across both crops and fields in promoting crop-income stability (Economics Program Progress Report 51). We used data from cultivator households in 6 study villages in 3 regions from 1975-76 to 1979-80. Crop-income instability was measured by the coefficient of variation of net crop income per hectare, which was calculated for each household.

Crop diversification effectively imparts stability to crop income in the dryland-farming villages of Sholapur and Akola districts. In the more highly irrigated villages of Mahbubnagar district, income stability and crop diversification are not highly associated.

The net effect of irrigation on crop-income stability depends on source of irrigation, ecological location, and level of development of irrigation facilities. In the Akola villages, both the amount of irrigated area and fluctuations in it were significantly associated with household crop-income instability. Most important in

Table 13. Dependence on Common Property Resources (CPRs) by indicated categories of rural households in selected villages in Rajasthan and Madhya Pradesh[1].

	Rajasthan		Madhya Pradesh	
Indicator	Labor, small farm household	Large farm household	Labor, small farm household	Large farm household
Households, %				
- meeting > 70 % grazing requirements from CPRs	97	24	82	25
- collecting food material from CPRs	41	3	77	0
- collecting fuel from CPRs	86	0	98	0
- collecting fodder from CPRs	36	3	55	5
- collecting timber, silt, and other natural resources from CPRs	12	36	10	45
- obtaining supplies and wage employment from CPRs during drought[1]		69	0	-
- using CPR water for irrigation	0	9	0	15
- consuming only CPR-food items that were collected and not purchased	39	0	50	0
CPR-based income as proportion of gross income[2] per household	42	15	-	-
Number of households	58	33	40	20

1. For data base, see Jodha 1983c. Information for the villages of Nagaur, Jodhpur, and Jaisalmer districts of Rajasthan is combined in this tabulation.
2. Gross CPR-based income includes the value of CPR products collected and 50% of the gross income from livestock raising. Data from Madhya Pradesh not yet analyzed.

explaining such instability across the 3 villages was variability in cropped area. Fluctuations in cropped area reduce the effectiveness of policies, such as crop insurance, which view yield stabilization as a means to achieve income stability.

Resource Management

The Role of Common Property Resources in Traditional Farming Systems

Common Property Resources (CPRs), such as community pasture, village forest, wasteland, ponds, tanks, rivulets, watershed drainages, and groundwater play significant roles in generating income and employment in rural areas. They complement private-resource-based farming systems. To document the contribution of CPRs, we conducted retrospective surveys in selected villages in Madhya Pradesh and updated earlier work in Rajasthan (Jodha 1983).

Common property enhances many aspects of rural villagers' welfare. Most animal grazing in the selected villages of the two states was on CPRs. Gathering CPR products such as fuel, fodder, timber, and foodstuffs provided 42 to 72 man days of employment annually per household.

Gross value of products (excluding livestock) collected from CPRs added between Rs 219 and 426 to annual income per household, which was 11 to 13% of their gross income. Given the heavy dependence on CPRs for grazing, if half of livestock income is attributed to CPRs, that proportion of CPR-generated income to total income would rise as much as 30 to 48% in these Rajasthan and Madhya Pradesh villages.

Analysis of survey data from 6 villages in 3 regions of peninsular India further revealed that poor households get 8% of their nutritional intake from CPR products, compared with 4% for richer households.

Labor and small-farm households relied more heavily on CPRs and derived much more employment, income, and nutrition from the CPRs than did other village households (Table 13). Despite their valuable growth and equity contributions, CPRs are rapidly declining in both area and productivity; our study of 24 villages in Madhya Pradesh and Rajasthan confirmed both trends (Table 14).

Table 14. The decline of Common Property Resources (CPRs) in selected locations of Rajasthan and Madhya Pradesh from 1953-54 to 1982-83.

	1953-54		1982-83	
Location (District, state, no. of villages)	CPR[1] in total land area (%)	Animal units (no./ 100 ha)	CPR[1] in total land area (%)	Animal units (no./ 100 ha)
Nagaur (Rajasthan, 2)	43	38	14	68
Jodhpur (Rajasthan, 2)	38	42	16	73
Jaisalmer (Rajasthan, 2)	67	12	482	192
Raisen (Madhya Pradesh, 10)	27	43	63	58
Vidisha (Madhya Pradesh, 8)	32	46	83	62

1. CPRs include village pasture, wasteland (including river banks and catchments of tanks) and village forest land. They exclude forest lands under government control.
2. Refers to 1963-64 and 1964-65, instead of 1982-83. Data for 1982-83 not available.
3. This excludes the areas of CPRs that are legally restricted from public use by government or panchayats in Madhya Pradesh; such areas may constitute 2 to 5 % of total area in different villages.

Composite Watershed Management on Alfisols

Low moisture-retention capacity of Alfisols limits their productivity in rainfed agriculture. However, substantial productivity increases are possible if water is available to be applied in some form of irrigation. For that reason, irrigation tanks are traditionally used by farmers in Alfisol areas to store runoff from monsoon rains for gravity irrigation of paddy grown in an area approximately as large as the area submerged by

Aerial view of a typical irrigation tank in Tamil Nadu, India. Such tanks can be highly profitable, but are silting up owing to deforestation and encroached on by increasing population.

the storage tank. Earlier research on tank irrigation in India has shown that such tanks can be very profitable; during the past two decades, however, tank irrigation has declined in many areas of India because of increased pressure on land, and also because the availability of new technologies permits access to groundwater at less cost than before.

In many instances, farmers plow up the tank bed and irrigate from wells both the land in the former tank bed and that in the former tank command area. But the increase in wells and the reduction in tanks for recharging aquifers means that groundwater becomes limiting. How can an improved system of groundwater management be developed with the help of recharge structures and wells for irrigation in place of, or in combination with, the traditional irrigation tank?

To answer that question, we built a mathematical model consisting of two parts. Part I simulates the hydrology of runoff and groundwater flows under different rainfall regimes, and Part II—superimposed on Part I—determines the optimal cropping system and economic returns, subject to constraints in groundwater availability, costs of lifting water, and other relevant factors.

That model, based on data collected from ICRISAT village-level studies at Aurepalle and from special-purpose surveys, was applied on a watershed of about 200 ha in Aurepalle village.

The results are summarized in Figure 4. Under purely rainfed conditions (system 1), a hectare on the watershed would produce net returns of Rs. 193 and provide 29 man days of employment. Well irrigation (system 2) considerably increases productivity; net returns as well as man days of employment would nearly double with 5 wells/100 ha and triple with 15 wells/100 ha. Adding to the available groundwater with the help of percolation structures increases productivity further, especially at high well densities.

Alternative policies for providing artificial groundwater recharge would increase net returns over those using wells without recharge tanks and depending solely on natural groundwater recharge. One recharge tank per well (system 3) increases net returns by 9 to 200% and raises employment 9 to 24%. An area of 3.7% under percolation structures, constant for all well densities (system 4), increases net returns by 18 to 33%, and adds 20 to 37% to employment. Putting the optimal area under percolation tanks (system 5) would yield 36% to 77% higher net returns, and raise employment 38 to 84%.

As well density increases, groundwater becomes more limiting and policies providing additional groundwater recharge structures are increasingly profitable. At well densities of about 5 wells/100 ha, natural groundwater recharge is sufficient to provide nearly all the water required for irrigation. At 10 to 15 wells/100 ha, about 50% higher net returns and 60% higher employment rates can be expected when 5 to 8% of the area is devoted to groundwater recharge structures, such as percolation tanks.

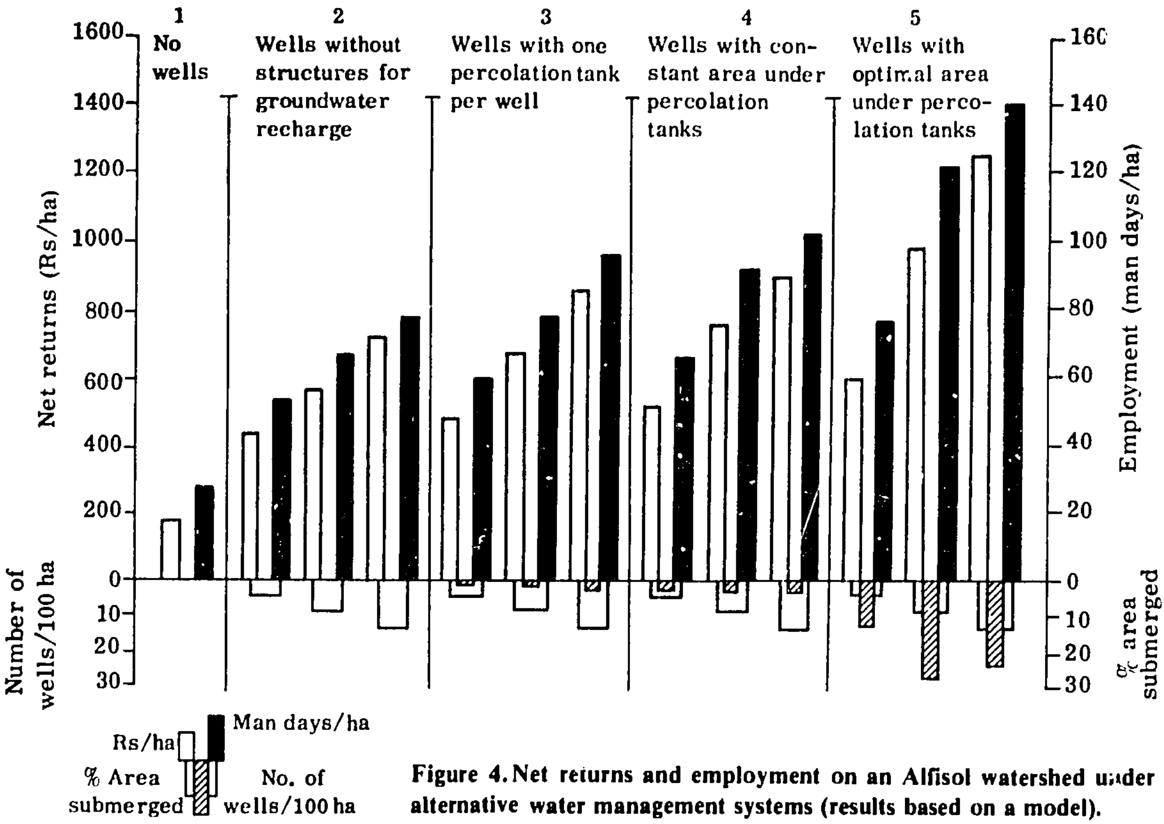

Figure 4. Net returns and employment on an Alfisol watershed under alternative water management systems (results based on a model).

Enhancing Productivity in Integrated Crop-Livestock Farming Systems

To identify and overcome constraints to enhancing productivity in integrated crop-livestock farming systems in Niger, we started collaborative research with International Livestock Center for Africa (ILCA) in April 1983. This research centers on agropastoral systems in the four ICRISAT study villages.

Results from preliminary surveys suggest that ruminant productivity is limited by lack of feed in the dry season, while diseases limit poultry production. Herd structure in small ruminant populations is similar to that found by ILCA investigators in Mali. But in the cattle population, the proportion of females is much lower, indicating less use of cattle for draft in the Niger study villages. This study is discussed in greater detail in the ILCA 1983 Annual Report.

Workshops, Conferences, and Seminars

International Workshop on Agricultural Markets in the Semi-Arid Tropics

Sponsored jointly by ICRISAT, Osmania University, and the International Geographical Union, this workshop was held 24-28 October at ICRISAT Center. The 74 participants included social scientists as well as policy makers and administrators representing ICRISAT and a range of countries such as China, Federal Republic of Germany, India, Japan, Mali, Niger, Nigeria, Thailand, United Arab Emirates, UK, and USA. The participants were divided into three working groups (periodic markets, public intervention, and equity and efficiency) and invited to identify policy implications and subjects that require research in the future. Their recommendations included specific and general topics that merit current research attention. Proceedings are in preparation and will be available from Information Services, ICRISAT.

Workshop on Farmers' Participation in the Development and Evaluation of Agricultural Technologies

The ICRISAT West Africa Economics Program, assisted through partial funding from International Development Research Centre (IDRC), held this workshop 20-25 September in Ouagadougou, in collabration with the Organization of African Unity/Semi-Arid Food Grains Research and Development (OAU/SAFGRAD) Farming Systems Unit and Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT). The workshop assembled 60 researchers from some 20 countries in Africa, Latin America, North America, Asia, and Europe to discuss methods to more effectively involve farmers in technology development and evaluation. Workshop participants represented a broad range of experience; there was nearly equal representation of technical and social science disciplines, and of French and English backgrounds.

Workshop papers and discussion were organized around four themes: theoretical and practical problems in establishing valid communication between researchers and farmers; farmers' input in the diagnosis of existing farming systems; involving farmers in evaluating prospective technologies; and farmers' participation in the modification and design of new technologies. The workshop included field visits to sites in three zones of Upper Volta where on-farm research is being conducted by ICRISAT, SAFGRAD, and IRAT. The proceedings are to be published by IDRC in French and English and will be available in 1984.

Workshop on Technology Options and Economic Policy for Dryland Agriculture: Challenge and Potential

The workshop, jointly sponsored by ICRISAT, the Indian Society of Agricultural Economics, and the All India Coordinated Research Project for Dryland Agriculture, was held 22-24 August at ICRISAT Center. Thirty-seven participants, including economists, bankers, and policymakers from all over India, attended the workshop. Twenty-two papers were presented on subjects such as inventory of agricultural technology, constraints and evaluations, agricultural research policy, and general policy. Proceedings will be available at a future date from the Indian Society of Agricultural Economics.

Workshop on Wastershed-Based, Dryland Farming in Black and Red Soils of Peninsular India

This workshop, organized jointly by the National Bank for Agriculture and Rural Development (NABARD), the Indian Council of Agricultural Research (ICAR), and ICRISAT, was held 3-4 October at ICRISAT Center. Seventy-three senior officials--drawn from the departments of agriculture of the Government of India and the states of Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra, ICAR, NABARD, and other leading banks--and 11 members of ICRISAT staff participated in the workshop. They endorsed the development of small watersheds as a key element in improving dryland agriculture, recognizing that the major limiting factor to agricultural production in dryland areas is water, not land. Proceedings are available from Information Services, ICRISAT.

Third Village-Level Studies Workshop

Jointly sponsored by ICRISAT and the Jawaharlal Nehru Krishi Viswa Vidyalaya (JNKVV), the workshop was held 29 September-2 October in Jabalpur and Bhopal, Madhya Pradesh, India to discuss the progress of village-level studies in Madhya Pradesh and at other locations and to develop plans for future work. Thirty-five scientists representing JNKVV, Gujarat Agricultural University and ICRISAT participated in the the 3-day workshop which was followed by a field visit to Papda, one of the VLS villages in Madhya Pradesh, and to Begumganj, where ICRISAT is conducting on-farm research on cropping systems.

Looking Ahead

We will continue to be involved in on-farm verification and transfer of the improved Vertisol technology options in India. Together with scientists in the Farming Systems Research Program and those in other institutions, we will initiate in-depth enquiries on several aspects of the improved Vertisol technology. Priority items on our research agenda are studies on the cost of, and demand for, wheeled tool carriers, prospects for harvesting water and supplementing irrigation to ensure postrainy-season wheat after rainy-season soybeans in Madhya Pradesh, the riskiness of agronomic component recommendations in representative Vertisol locations, and the whole-farm impact of improved Vertisol technology in Madhya Pradesh.

Several other areas of technology assessment also will receive greater attention in 1984. We will complete research on the interregional adoption of hybrid sorghum and pearl millet in major producing areas of India. We also plan to start research—jointly with scientists in our Groundnut Improvement Program—on the economics of fungicide control and foliar-disease resistance.

In Upper Volta, the fertilizer tests will be repeated in 1984 with an increased number of observations. The data will be further analyzed to identify the principal microenvironmental and management factors that explain variation in fertilizer response and to estimate the most profitable fertilizer rates. We will also repeat the program of farmer tests of contour bunding in collaboration with FDR next year. In Niger, we hope to carry out fertilizer tests for the third year in 1984. Data collected on cereal straw use, cowpea seed availability, and planting decisions will be analyzed. Results from baseline studies in Mali will also be reported in 1984.

By June 1985 we will have completed 10 years of ICRISAT village-level studies in India. Increasingly we are using data from those studies to evaluate the dynamics of agricultural development. They will provide us, for example, a unique opportunity to report in 1984 on the stability consequences of crop insurance. We will also start in study villages retrospective surveys, which are to be the basis for a World Bank sponsored investigation on rural financial intermediation and socioeconomic mobility.

We will give greater currency in our behavioral research to viewing the household as both a producing and a consuming unit. Informal linkages with social scientists in the Population Council, New York, have helped us probe deeper into the effects of public works programs and household adjustments to agricultural and life-cycle risks in India's SAT. Additionally, we plan to use the VLS data to assess the impact of fragmentation and prospects for land consolidation, which will have a bearing on the success or failure of a watershed approach to resource management.

In Upper Volta, we are examining seasonal patterns and determinants of cereal purchases and sales. Interdisciplinary research between anthropology and economics will continue to look at how interannual and interseasonal variation in cereal production and interactions are related to weight fluctuations, morbidity, and labor availability among household members. Adjustment mechanisms, such as reserve stocks, noncommercial food transfers, and seasonal outmigration, will also receive attention.

In Niger, collaborative research with ILCA will examine more closely dimensions of crop-livestock farming systems in the ICRISAT study villages.

Finally, work will begin on modeling household production and market behavior with the aim of estimating income and price elasticities of demand for cereals among rural households in Upper Volta and Niger. This research is being carried out in a collaborative project involving economists in the International Food Policy Research Institute (IFPRI) and IRAT/GERDAT.

We will use special-project funding to support research on composite watershed management, to be undertaken jointly with scientists in the

Farming Systems Research Program. The work on common property resources will be extended to other areas of India's SAT, and will be carried out increasingly within the framework of a watershed-management approach. Economists will also participate in planning interdisciplinary farming-systems research in agroforestry, which may begin in 1984.

A six-week training program for social scientists working in national agricultural research institutions in SAT countries will be held in May 1984 at ICRISAT Center.

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TRAINING

Training programs completed in 1983 (Table 1) involved 118 agricultural scientists, research technicians, and extension personnel from 37 countries (Table 2).

Postdoctoral Programs

Postdoctoral international interns completed research projects in pearl millet microbiology, groundnut virology, pigeonpea cultivar responses to off-season planting, development of a computerized pedigree management system, and on-farm technology testing and adaptation.

Postdoctoral research fellows studied causal fungi in sorghum grain mold, calcium and water relations in groundnut, and mycotoxin contamination of groundnut pods and seeds.

In-Service Fellows

In-service fellows completed short periods of study in disease screening techniques in pearl millet, sorghum pathology, yellow mosaic virus of legumes, modeling techniques in agroclimatology, and in analysis and management of rainfed agriculture related to farming systems.

Research Scholars

Research scholars were supervised by research scientists and training staff for their PhD or MSc thesis research. They studied problems related to sorghum genetics and combining ability for improved sorghum grain quality, hybrid vigor utilizing male sterility in pigeonpea, cropping systems fertility, nitrogen fixation estimations, climatological modeling for pearl millet responses, mycorrhiza, root exudates, groundnut physiology and plant growth, use of pheromones to trap insects, analytical methods for mycotoxin identification, entomology collection procedures, land treatment in relation to runoff, sorghum genotype selection for intercropping, light interception in relation to water use and pearl millet dry-matter production, plant tissue and soil analysis techniques, water balance studies in improved land and water management systems and selected cropping systems, analysis of processed grains, economics of water management systems, response of groundnut to moisture stress, groundnut genotype influence on nitrogen-fixing organisms, and studies of viruses on pigeonpea, and groundnut.

Table 1. Number in long-term training in ICRISAT Center during 1983 and total weeks of participation.

Category	Completed	Weeks	Continuing
International Interns	4	394	4
Research Fellows	3	309	5
In-service Fellows	12	53	0
Research Scholars	22	1089	15
In-service Trainees	74	1410	8
Apprentices	3	39	2
Total	118		34

In-Service Trainees.

The 74 in-service trainees from 29 countries accounted for the largest number of weeks of training—in crop improvement, crop production, and farming systems. More than 90 ICRISAT scientists were involved in training activities.

Short-Term Courses

Special short-term training was provided to Indian scientists, extension officers, bank agricultural officers, development officers, and policy makers—totaling 138—from more than four states in India. They were trained in cropping systems technologies based on a broadbed-and-

Facets of training offered at ICRISAT Center: top left, international intern working on a microbiology test; top right, research scholar discusses pigeonpea crop with ICRISAT breeders; bottom left, in-service trainees plan harvest of groundnut plots; and bottom right, research fellow sets up equipment for physiology experiment.

Table 2. Number of participants—by region and country—who completed a long-term training program in 1983.

Region/Country	No.
Western Africa	
Benin	1
Gambia	3
Ghana	2
Mali	3
Niger	1
Nigeria	2
Senegal	4
Sierra Leone	1
Upper Volta	2
Eastern Africa	
Egypt	1
Ethiopia	7
Kenya	3
Somalia	1
Sudan	5
Uganda	5
Southern Africa	
Botswana	1
Malawi	5
Mozambique	1
Zimbabwe	1
Asia	
Bangladesh	1
Burma	1
China	4
India	31
Indonesia	2
Iraq	1
Philippines	1
Thailand	10
Yemen Arab Republic	1
Southern America	
Brazil	2
El Salvador	1
Mexico	1
Others	
Australia	1
Canada	1
Federal Republic of Germany	2
Netherlands	3
United Kingdom	1
United States	5
Total	118

furrow system for use in deep Vertisol regions with assured rainfall.

A special 6-week course on *Rhizobium* technology for legumes was held in Sept-Oct 1983. Thirteen participants from four countries (Egypt, India, Indonesia, and Sudan) attended the course offered by NifTAL (Nitrogen-fixation by Tropical Agricultural Legumes) instructors from the University of Hawaii, USA and ICRISAT microbiologists.

Continued contacts with former trainees have indicated an increased interest in obtaining germplasm, publications, and personal consultation from ICRISAT to facilitate their active participation in national research and extension programs.

Publications

Institute Publications

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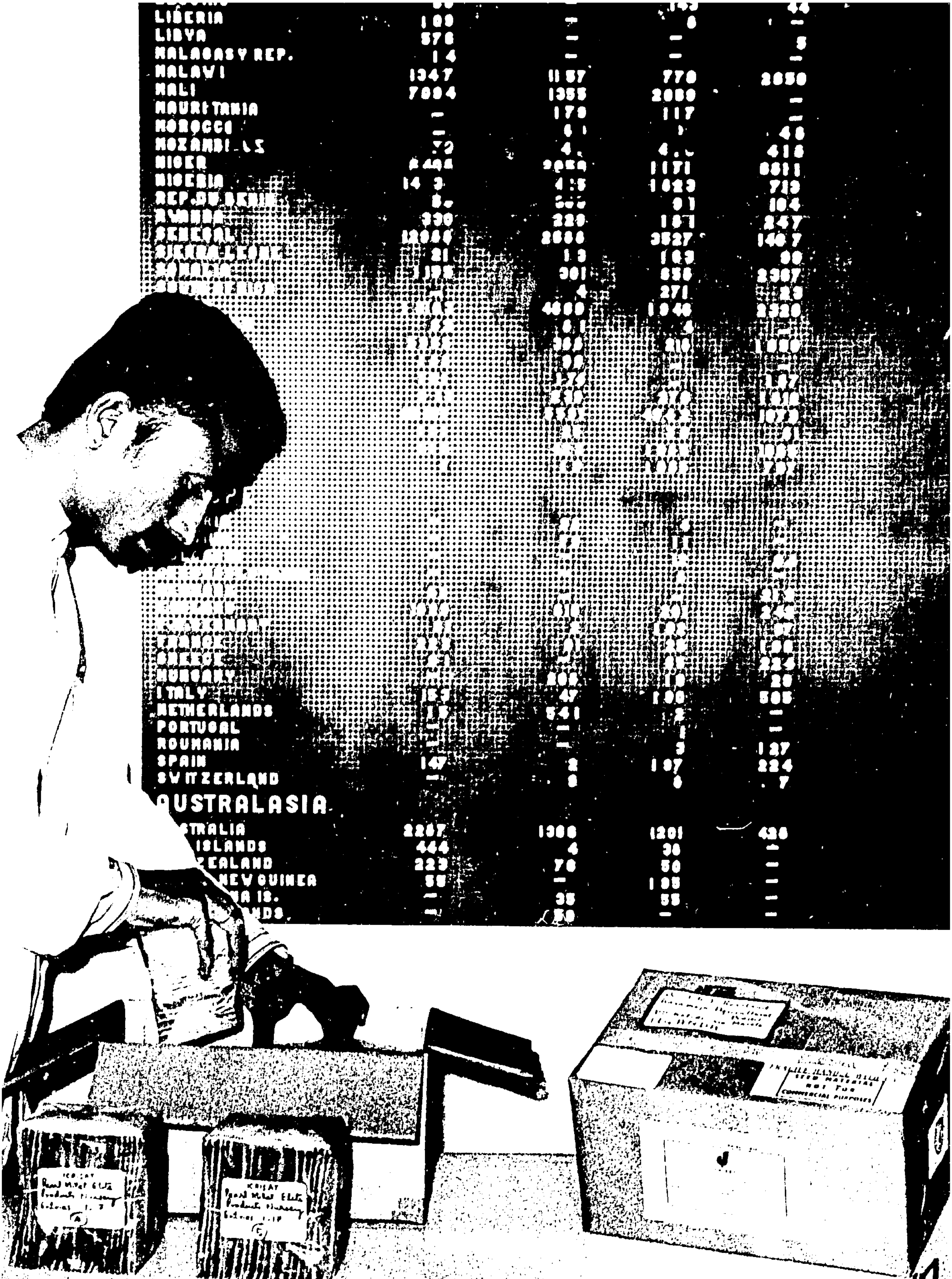
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MALI 7894 1355 2080 —
MAURITANIA — 179 117 —
MOROCCO — 61
MOZAMBIQUE 418
NIGER 2059 1171 8011
NIGERIA 1023 719
REP. DU BENIN 91 104
RWANDA 330 229 187 247
SENEGAL 2886 3527 1467
SIERRA LEONE 21 13 163
SOMALIA 301 858 2367
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4600 1946 2320
HUNGARY
ITALY 47 100 505
NETHERLANDS 541 —
PORTUGAL —
ROUMANIA 127
SPAIN 147 2 187 224
SWITZERLAND — 8 7
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ZEALAND 223 78 50 —
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Pearl Millet Elite
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Contents

Plant Quarantine 349
Plant Material Exports 349
Plant Material Imports 352
Postentry Quarantine 352

Statistics Unit 352

Computer Services 354
Development 354
Looking Ahead 355

Library and Documentation Services 355
Acquisition 355
Documentation Services 355
Sorghum and Millets Information Center (SMIC) 355

Publications 356

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RESEARCH SUPPORT ACTIVITIES

Plant Quarantine

The Plant Quarantine Unit plays an important role in supervising ICRISAT mandate crops grown in the post-entry quarantine isolation area (PEQIA). Imported seeds are released by the National Plant Quarantine Services for use in India and for export to various countries only after their good health is assured.

Examining the huge number of seed samples by international standards to meet plant-quarantine regulations of importing countries has been the major work of the Plant Quarantine Unit. Groundnut seeds were Enzyme Linked Immunosorbent Assay (ELISA) tested for peanut mottle virus (PMV) by the Groundnut Improvement Program. Legume seeds were X-rayed for hidden insect infestation. Additionally, all seeds except those due to be chemically analyzed were treated before despatch with insecticides and fungicides.

Plant Material Exports

During the year, 75 533 seed and plant samples of sorghum, pearl millet, chickpea, pigeonpea, groundnut, minor millets, and other crops were exported to scientists and cooperators in 93 countries. Seed exports included material from breeding nurseries, varietal and hybrid yield trials, *Rhizobium* innoculation trials, pest and disease nurseries, and germplasm accessions from the ICRISAT gene bank, along with genotypes for chemical and food-quality analyses, and physiological studies.

Other crop samples exported were maize, teosinte, and *Heteropogon* for the downy mildew (*Peronosclerospora sorghi*) host-differential nurseries. In addition, dried herbarium specimens, samples of sorghum straw, *Rhizobium* cultures, and sorghum plant material infected with oospores of *Peronosclerospora sorghi* were exported for scientific investigations. Complete information on the plant and seed materials exported is presented in Table 1.

Quarantine staff examine seed samples very carefully to ensure no diseased or insect damaged samples are imported.

Treating ICRISAT seed samples with pesticides before export.

Table 1. Plant material exports during 1983.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
AFRICA							
Botswana	3558	16			1		13
Cameroon		2134	8				
Cape Verde Islands				72			
Chad				5			
Comoros Islands				24			
Egypt	129		182		20		
Ethiopia	301		552	50	45		10
Gambia	69						
Ghana	77	3		10	80		
Ivory Coast					40		
Kenya	699		192	364			
Malawi	233	13	216	162	392	3	
Mali	529	22	10	146	10	31	2
Mauritania		64					
Mauritius			22				
Morocco	240						
Mozambique	277						20
Niger	229	2774					
Nigeria	346	313		440	142		13
Rwanda	69			48			
Senegal	705	305			1		3
Sierra Leone	20	20	4	27			
Somalia	622				14		
South Africa	62			99			
Sudan	1476	400	230	35	42		7
Swaziland					10		
Tanzania	63		60	116			
Tunisia			242				
Uganda	442	100		51			22
Upper Volta	1262	13		1	1		3
Zaire	16	18		8			20
Zambia	9708	466	74	6	5	185	3
Zimbabwe	10545	59			164		
ASIA							
Bangladesh			667	6	19	202	11
Burma	69		134		1		3
China	82				181		27
Indonesia	69	4		345	2	12	21
Japan			1		2		6
Korea			6		26		
Malaysia	21			38	31		9

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Nepal	138		650	14			
Pakistan	1068	365	7223	157	280		6
Philippines	1351	6	173	113	3		8
Qatar	23	20					
Saudi Arabia	103			24	5		
Sri Lanka	90				124		
Syria			447	2			33
Taiwan				4			
Thailand	772	24	63	185	251	32	19
USSR	4	6					
Yemen Arab Republic	281		40	10			20
THE AMERICAS							
Antigua				29			
Argentina	682		182		1		20
Bahamas				18			
Belize	69						
Brazil	423		114	20	13		15
Canada			292	12	16		
Chile			394				
Colombia	69				42		
Dominican Republic	134			18			
El Salvador	238			5	22		
Guatemala	69						
Guyana					1		3
Haiti				18			
Honduras	279	4					
Jamacia				24			
Mexico	2735		668	29	36	30	20
Nicaragua	69	4		4	4		
Peru			182		1		6
Puerto Rico				36			3
Surinam	138				50		3
Trinidad				40	1		3
Uruguay	100	2					
USA	625	117	1410	62	284		34
US Virgin Islands			15	17	15		
Venezuela	251						10
EUROPE							
Bulgaria			64				3
Czechoslovakia	30	10	30	10			

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Denmark	48		8				3
France	521	5			20		14
Germany (Federal Republic)		7		4	9	6	
Greece			182				
Italy	194		5			30	
Netherlands	100	98					539
Portugal			98		44		
Spain			253	1			
Switzerland							1
UK	94	79	8	11	2424		465
Yugoslavia	52						
AUSTRALASIA							
Australia	70	95		138	10		155
New Zealand	1			1			
Papua New Guinea					70		
Pacific Islands (Trust Territory)	6						
Total	44879	5440	15093	3055	4959	528	1579

Plant Material Imports

The National Plant Quarantine Service at the Central Plant Protection Training Institute (CPPTI), Hyderabad, released to ICRISAT 6054 seed samples, groundnut plants, *Atylosia* spp, and dried herbarium specimens of mandate crops. Additionally 228 seed samples of minor millets from Kenya, UK, and Zimbabwe for ICRISAT's gene bank were released by the National Bureau of Plant Genetic Resources (NBPGR), New Delhi. Details of the imports are given in Table 2.

Postentry Quarantine

In all, 5635 samples of sorghum, pearl millet, chickpea, pigeonpea, groundnut, and minor millets were planted in the PEQIA. Included was a special planting of 399 chickpea samples comprising of F_3 progenies of single plants selected for ascochyta blight resistance from ICARDA.

Suspect plants, when found, are rogued and incinerated. Only seeds from healthy plants were released to research programs.

Statistics Unit

The Statistics Unit advises ICRISAT staff on planning experiments and analyzing data. The number who consulted us rose during 1983 to an average of more than 60 per month. Many data sets were processed for scientists and several GENSTAT and Fortran computer programs were developed for specific processing needs.

We reviewed various program reports and papers for the Editorial Committee. Experimental results from sites, especially in Africa, are variable. Our principal statistician visited African stations in 1983 to discuss trial designs, field experimental techniques, and methods of processing results, which may assist with accounting for this variability.

Table 2. Plant material imported during 1983.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
AFRICA							
Botswana	2						
Burundi	96						
Cameroon		16					
Ethiopia	317						
Kenya	111			259		6	
Malawi	7						
Mali	273	15					
Niger		82					
Rwanda	167						
South Africa	122	58					
Sudan	239	7					
Upper Volta		198					
Zimbabwe	274	108			54	187	107
ASIA							
Bangladesh				20			
Indonesia					7		
Nepal			1				
Syria			407				
AMERICA							
Mexico		2					
USA	561		766		380		
EUROPE							
Belgium				2			
France	956	199					
Netherlands					4		
Spain			41				
UK	80	66		10		35	
AUSTRALASIA							
Australia		3	1	36			
Total	3205	754	1216	334	438	228	107

Discussions with scientists enabled the following studies.

1. We developed a simultaneous joint-scaling test for several correlated traits to estimate generation mean parameters.
2. The Papadakis nearest-neighbor technique was assessed with data from screening genotypes for disease resistance.
3. We developed a statistical analysis of data from intercropping experiments, using sole and intercrop data and several error correlation structures.
4. Statistical tests were developed to compare the coefficients of variations in income dis-

tributions belonging to univariate and multivariate log normal and Pareto distribution families.

The Institute benefited from a consultant's visit to investigate techniques dealing with missing and defective data in the analysis of variance, the analysis of nonorthogonal data, and *Striga*-count data.

We participated in several conferences, symposia, and scientific meetings and prepared technical reports for scientists' use.

Computer Services

The Computer Services Unit provides timesharing services to ICRISAT personnel through the VMS operating system on a DEC VAX-11/780 computer system. We develop interactive systems, provide data-entry services, install software packages, and conduct seminars on using the computer for ICRISAT scientists, administrators, and service departments.

Development

The ICRISAT Data Management and Retrieval System (IDMRS), previously available on our PDP-11 computer, was converted, with improvements, for use on the VAX. It is used primarily to manage the Genetic Resources Units' germplasm data. As in previous years, the locally developed statistical package, CRISP, was improved and modified when possible. We completed a Pedigree Data Base Management System in May 1983, in collaboration with our chickpea and pigeonpea breeders.

The 45 terminals we added in May 1983 provided computer access to many more people, and at least one terminal for nearly every subprogram in ICRISAT. The improved computer accessibility, coupled with 98% uptime, increased computer usage 52% over the previous year. But as the number of simultaneous users increased, system performance decreased. Despite efforts to improve the situation, system performance is not yet satisfactory when more than 40 users are online. Adding new, improved terminal interfaces in 1984 should improve the situation.

A new version of the operating system, VMS Version 3 significantly improved services in April 1983 and made many additional tools available to more accurately monitor usage. When we added new terminals, we also acquired two VT180 microcomputers, which permitted the computer services staff to become familiar with CP/M, the operating system used on many microcomputers; WordStar, a word processing package; and Multiplan, a spreadsheet calculator.

We also developed new systems to manage mailing lists and workshop/seminar events, and upgraded the existing payroll system to prepare payrolls for the Regular Work Force and Continuous Farm Labor. A system to manage vehicle fuel records was developed for ICRISAT's Purchase and Supplies Division. DATATRIEVE, a retrieval system available from the computer manufacturer, is being tested for inventory control of spare parts, and other administrative applications. The work-order system developed in 1982 was further improved in 1983.

Use of the computer system's word processing capabilities has increased so much that major ICRISAT publications and all research papers are prepared with computer assistance. An interface between the computer and the phototypesetter permits direct transfer of documents from computer to typesetter. A major part of the 1982 Annual Report was initially prepared on computer and transferred directly to the typesetter. Computer Services also organized three courses to teach word processing to ICRISAT staff.

A major thrust in 1983 was ordering microcomputers, recommended by the Computer Services Advisory Committee. The search for suitable equipment and accessories ended with orders for 12 Osborne Executive microcomputers, 9 Epson FX-80 printers, and 7 NEC spinwriter quality printers. Additionally 6 Epson HX-20 microcomputers and 5 Polycorders were purchased for use in the field as direct data capture devices.

A new computer system, a VAX-11/750, was ordered for use by administrative departments. ICRISAT's first computer will be sold in 1984.

The department head attended a DEC User's Society meeting in October 1983 in Las Vegas, and a workshop in London on evaluating microcomputers. Two other staff members attended the annual Computer Society of India meetings. One staff member attended a workshop on management skills for EDP executives, and two staff members attended a two-week course on systems analysis and design, both organized by the Computer Maintenance Corporation of India. One staff member attended a two-day course on decision-support systems in Ahmedabad, India.

Looking Ahead

Emphasis in 1984 will be on developing and acquiring software to support administrative functions. All remaining aspects of fiscal accounting support will be developed to complement the payroll system, and purchase order and inventory control will be computerized. We also plan a major revision of the locally developed, statistical package, CRISP. It will be necessary to educate staff in the use of the newly acquired microcomputers.

Library and Documentation Services

Acquisition

The steady growth rate that the Library has reached permitted us to develop a predictable acquisitions policy. Acquisition of nonconventional literature has improved considerably as a result of closer links established with institutions, libraries, and documentation centers in the SAT. Data on acquisitions during 1983 are given in Table 3.

Table 3. Status of acquisitions, ICRISAT Library, 1983.

Documents	Additions during 1983	Total holdings (Dec 1983)
Books and reports	1481	18177
Bound volumes of periodicals	897	11479
Annual reports	138	805
Reprints, photocopies, etc.	2277	4227

Documentation Services

We continued the Selective Dissemination of Information (SDI) service to ICRISAT Center scientists, scientists in the African cooperative programs, and those in other national and international programs in India and Africa. The consensus of those who evaluated the service in October 1983 was that it serves a useful purpose.

Sorghum and Millets Information Center (SMIC)

Computerization. During 1983 we developed a software package called SOMIN to generate author and subject indexes to SMIC bibliographies. The package was used to produce hard copy of Sorghum Bibliography indices for 1977-80.

Programs were developed to create and update the 1982 Directory of Sorghum and Millets Research Workers.

Bibliographies. Millets bibliographies for 1970-76 and 1977-80 were published in 1983. Compilation work for the Sorghum Bibliography for 1977-80 was completed and work was started on annual annotated bibliographies on Sorghum and Millets beginning with 1981.

Special-subject reviews. The special-subject review entitled, 'A Review of Fertilizer Use Research for Sorghum in India', carried out as SMIC activity, is being edited for publication as ICRISAT Research Bulletin No. 8 in 1984. SMIC provided information support for a similar project on *Striga*. The work started in 1982 on 'Agrometeorological Studies on Sorghum and Millets' was continued, a large number of references have been assembled and computerized prior to being issued as a bibliography.

Document delivery services. SMIC provided copies of 962 papers in its collection to scientists throughout the SAT. Three issues of the SMIC Newsletter in English and three in French were published and distributed to more than 1000 addresses during the year.

Publications

During the year 96 papers prepared by ICRISAT scientists were reviewed and approved by the Institute's Editorial Committee and submitted to scientific journals. Eighteen of these were published by December and 30 others were accepted for publication. Forty-three papers on various aspects of ICRISAT's work were approved and presented at conferences and workshops, of which 7 were published and 17 others are in press.

Institute publications are listed at the end of the appropriate section of this Report. General audience publications are listed below. Copies of all Institute publications are available from Information Services, ICRISAT.

Institute Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Research Highlights 1982. Patancheru, A.P. 502324, India: ICRISAT. 44 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Progrès de la recherche 1982. Patancheru, A.P. 502324, India: ICRISAT. 44 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Annual Report 1982. Patancheru, A.P. 502324, India: ICRISAT. 440 pp.

Publications issued during 1983, copies are available from Information Services, ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Laying of the foundation stone: ICRISAT Sahelian Center, Sadoré, Niger 16 Aug 1983. Patancheru, A.P. 502324, India: ICRISAT. 12 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Allocutions: Cérémonie de la pose de la première pierre du centre sahélian de l'ICRISAT. 16 août 1983 Sadoré, Niger. Patancheru, A.P. 502324, India: ICRISAT. 12 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. ICRISAT and the Commonwealth. Patancheru, A.P. 502324, India: ICRISAT. 24 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Royal visit to ICRISAT Center: a souvenir. Patancheru, A.P. 502324, India: ICRISAT. 8 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. ICRISAT Publications Catalog. Patancheru, A.P. 502324, India: ICRISAT. 24 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), **Sorghum and Millet Information Center.** 1983. Millets bibliography 1970-76. Patancheru, A.P. 502 324, India: ICRISAT. 173 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), **Sorghum and Millets Information Center.** 1983. Millets bibliography 1977-80. Patancheru, A.P. 502 324, India: ICRISAT. 226 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), **Sorghum and Millets Information Center.** 1983. Sorghum bibliography 1974-76. Patancheru, A.P. 502 324, India: ICRISAT. 200 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), **Sorghum and Millets Information Center.** 1983. SMIC Newsletter nos.10, 11, and 12 (Dutta, S., ed..) Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), **Sorghum and Millets Information Center.** 1983. La Lettre du SMIC nos.10, 11, et 12 (Dutta, S., éd..) (In Fr..) Patancheru, A.P. 502 324, India: ICRISAT.

Journal Article

Gilliver, B., and **Pearce, S.C.** 1983. A graphical assessment of data from intercropping factorial experiments. Experimental Agriculture 19:23-31.

Conference Papers

Singh, M., and **Gilliver, B.** 1983. Statistical analysis of intercropping data using correlated error structure. Presented at the 44th session of the International Statistical Institute Conference, 12-22 Sept 1983, Madrid, Spain. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Restricted distribution.)

Sinha, P.K., **Dutta, S.**, and **Prasannalakshmi, S.** 1983. Pragmatic approach to subject indexing. Presented at the 20th DRTC Annual Seminar, 21-25 Feb 1983, Bangalore, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Restricted distribution.)

Acronyms and Abbreviations Used in this Annual Report

ACT	Arhar Coordinated Trial
ACT-1	Early Maturity Arhar Coordinated Trial
ACT-2	Medium Maturity Arhar Coordinated Trial
ACT-3	Late Maturity 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 (India)
AYT	Advanced Yield Trials
BBF	Broadbed and Furrow
BND	Bud Necrosis Disease
BP	Base Populations
CATIE	Centro Agronomico Tropical de Investigacion y Ensenanza (Costa Rica)
CD	Controlled Droplet
CDA	Controlled Droplet Applicators
CE	Catechin Equivalent
CERCI	Centre d'Expérimentation du Riz et Cultures Irriguées (Upper Volta)
CGIAR	Consultative Group on International Agricultural Research
CIABN	Chickpea International Ascochyta Blight Nursery
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CIBC	Commonwealth Institute of Biological Control
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (Mexico)
CIVT	Cowpea International Variety Trial
CIYT	Chickpea International Yield Trial
CIYT-L	Chickpea International Yield Trial, Large-seeded
CIYT-W	Chickpea International Yield Trial-Winter
CLAIS	Comision Latinoamericano de Investigadores en Sorgo (Guatemala)
CMC	Computer Maintenance Corporation (India)
CPPTI	Central Plant Protection and Training Institute (India)
CPRs	Common Property Resources
CSH	ICRISAT Sorghum Hybrid
CSIR	Council of Scientific and Industrial Research (India)
CV	Coefficient of Variation
cv	cultivar
DAE	Days After Emergence
DAP	Days After Planting
DAS	Days after Sowing
DEC	Digital Equipment Corporation
DM	Downy Mildew
DMN	Downy Mildew Nursery
EACT	Early Arhar Coordinated Trial
EC	Emulsifiable Concentrate
ELISA	Enzyme-Linked Immunosorbent Assay

ELS	Ergot-Low Susceptible
EMD	Early Moisture Deficits
EPAY	Early Pigeonpea Adaptation Yield Trial
EPSRY	Early Pigeonpea Sterility Mosaic Resistant Yield Trial
ER	Ergot-Resistant
ES	Empirical Screening
ET	Evapotranspiration
EUF	Electro-Ultra Filtration
EXACT	Extra-early Arhar Coordinated Trial
FAO	Food and Agriculture Organization of the United Nations
FDR	Fonds de Développement Rural (Upper Volta)
FET	Final Evaluation Trial
FSRP	Farming Systems Research Program
FYM	Farmyard Manure
GCA	General Combining Ability
GCVT	Gram Coordinated Variety Trial
GDD	Growing Degree Days
GERDAT	Groupement d'Etudes et de Recherches pour le Développement de l'Agronomie Tropicale (France)
GIET	Gram Initial Evaluation Trial
GIP	Groundnut Improvement Program
GRU	Genetic Resources Unit
GS	Growth Stage
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Federal Republic of Germany)
HAU	Haryana Agricultural University (India)
HF	High Fertility
IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources (Italy)
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas (Syria)
ICGM	ICRISAT Groundnut Malawi Numbers
ICGS	ICRISAT Groundnut Synthetic
ICMH	ICISAT Millet Hybrid
ICMPES	ICRISAT Millet Pathology Ergot Sib-bulk
ICMS	ICRISAT Millet Synthetic
ICMV	ICRISAT Millet Variety
ICRRWN	International Chickpea Root Rots/Wilt Nursery
ICSN	International Chickpea Screening Nursery
IDMRS	ICRISAT Data Management and Retrieval System
IDRC	International Development Research Centre (Canada)
IEVT	Initial Experimental Variety Trial
IFAD	International Fund for Agricultural Development (Italy)
IFDC	International Fertilizer Development Center (USA)
IFPRI	International Food Policy Research Institute (USA)
IIA	Indole Acetic Acid
IITA	International Institute of Tropical Agriculture (Nigeria)
IIUCWRRN	ICRISAT-ICAR Uniform Chickpea Wilt/Root Rots Nursery

IIUTPABR	ICAR-ICRISAT Uniform Trials of Pigeonpea Alternaria Blight Resistance
IIUTPPBR	ICAR-ICRISAT Uniform Trials of Pigeonpea Phytophthora Blight Resistance
IIUTPSMR	ICAR-ICRISAT Uniform Trials of Pigeonpea Sterility Mosaic Resistance
IIUTPWR	ICAR-ICRISAT Uniform Trials of Pigeonpea for Wilt Resistance
ILCA	International Livestock Centre for Africa (Ethiopia)
IMZAT	ICRISAT Pearl Millet African Zone–A Trial
INIA	Instituto Nacional de Investigaciones Agricolas (Mexico)
INRAN	Institut National de Recherche Agronomique du Niger
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA)
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
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (France)
IRRI	International Rice Reseach Institute (Philippines)
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center (Niger)
ISDMN	International Sorghum Downy Mildew Nursery
ISFQT	International Sorghum Food Quality Trials
ISGMN	International Sorghum Grain Mold Nursery
ISHAT	International Sorghum Hybrid Adaptation Trials
ISLDN	International Sorghum Leaf Disease Nursery
ISMN	International Sorghum Midge Nursery
ISRA	Institut Sénégalais de Recherche Agricole
ISSFN	International Sorghum Shoot Fly Nursery
ISVAT	International Sorghum Variety Adaptation Trials
ITCZ	Intertropical Convergence Zone
IVMT	Improved Vertisol Management Technology
JNKVV	Jawaharlal Nehru Krishi Viswa Vidyalaya (India)
LADTSYT	Latin American Drought Tolerant Sorghum Yield Trial
LAEVSYT	Latin American Elite Variety Sorghum Yield Trial
LAI	Leaf Area Index
LARSYT	Latin American Rainfed Sorghum Yield Trial
LER	Land Equivalent Ratio
LF	Low Fertility
LPAY	Late-Maturity Pigeonpea Adaptation Yield Trial
LPD	Leaf and Plant Death
LS	Line Source
MPAY	Medium Pigeonpea Adaptation Yield
MPSRY	Medium-Maturity Pigeonpea Sterility Mosaic Resistant Yield Trial
MPUB	Medium-Maturity Pigeonpea Unselected Bulk
MPWRY	Medium-Maturity Pigeonpea Wilt-Resistant Lines Yield Trial
NAA	Naphthalene Acetic Acid
NABARD	National Bank for Agriculture and Rural Development (India)
NBPGR	National Bureau of Plant Genetic Resources (India)

NBRE	Napier Bajra Root Extract
NEC	New Early Composite
NEDM	Nitrogen Efficiency for Dry-Matter Production
NEG	Nitrogen Efficiency for Grain Production
NIN	National Institute of Nutrition (India)
NSS	National Sample Survey Organization (India)
NSSL	National Seed Storage Laboratory (USA)
NifTAL	Nitrogen-fixation by Tropical Agricultural Legumes
ODA	Overseas Development Administration (UK)
OFVT	On-Farm Verification Trials
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer (France)
PARP	Partially-Acidulated Rock Phosphate
PAU	Punjab Agricultural University (India)
PAY	Pigeonpea Adaptation Yield
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (Panama)
PCT	Population Cross Trial
PCV	Peanut Clump Virus
PE	Potential Evapotranspiration
PEQIA	Post-Entry Quarantine Isolation Area
PI	Panicle Initiation
PMAHT	Pearl Millet Advanced Hybrid Trial
PMAST	Pearl Millet Advanced Synthetic Trial
PMEHT	Pearl Millet Elite Hybrid Trial
PMHT	Pearl Millet Hybrid Trial
PMV	Peanut Mottle Virus
PON	Pigeonpea Observation Nursery
PSSFN	Preliminary Sorghum Shoot Fly Nursery
PVP	Polyvinylpyrrolidone
PYT	Preliminary Yield Trials
R	Multiple Correlation Coefficient
RH	Relative Humidity
RP	Rock Phosphate
RPIP	Regional Pulse Improvement Project
RRL	Regional Research Laboratories (India)
rse	residual standard error
SADCC	Southern African Development Coordination Conference
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	Semi-Arid Tropics
SBSSPN	Sorghum Breeding Sorghum Stem Borer Nursery
SCA	Specific Combining Ability
SDI	Selective Dissemination of Information
SDS	Soft-Dough Stage
SE	Standard Error
SEPON	Sorghum Elite Progeny Observation Nursery
SM	Sterility Mosaic
SMIC	Sorghum and Millets Information Center (India)
SMSS	Soil Management Support Services

SORGF	Sorghum Simulation Models
SPR	Soil Penetration Resistance
SRC	Smut-Resistant Composite
TDM	Total Dry Matter
TMV	Tomato Mottle Virus
UAS	University of Agricultural Sciences (India)
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UPN	Uniform Progeny Nursery
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VAM	Vesicular Arbusclar Mycorrhiza
VLS	Village-Level Study
VMS	Virtual Memory System
WAE	West African Early
WAON	West African Observation Nursery
WARDA	West Africa Rice Development Association
WART	West African Regional Trial
WC	World Composite
WSP	Water-Soluble Phosphorus
WTC	Wheeled Tool Carrier
WUE	Water-Use Efficiency

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France

ICRISAT Senior Staff—as of Dec 1983

Administration

L. D. Swindale, Director General
J. S. Kanwar, Director of Research (returned from sabbatic leave April)
R. W. Gibbons, Director of Research (until April)
C. R. Jackson, Director for International Cooperation (from January)
M. G. Wedeman, Principal Administrator
S. P. Ambrose, Principal Government Liaison Officer (from June)
B. C. G. Gunasekera, Principal Soil and Water Scientist (International Cooperation)
S. J. Phillips, Special Assistant to Director General for Educational Affairs (from June)
V. Balasubramanian, Executive Officer to Director General
Joyce Gay, Administrative Secretary to Director General
Sunetra Sagar, Administrative Secretary to Director of Research
S. Krishnan, Senior Administrative Officer (International Cooperation)
D. Mitra, Fiscal Manager
A. Banerji, Assistant Manager (Fiscal)
V. S. Swaminathan, Senior Accounts Officer
A. N. Venkataswamy, Accounts Officer
C. P. Rajagopalan, Accounts Officer
B. K. Johri, Personnel Manager
N. S. L. Kumar, Senior Personnel Officer
P. Suryanarayana, Personnel Officer
R. Vaidyanathan, Purchase and Stores Manager
K. P. Nair, Senior Purchase Officer
D. K. Mehta, Stores Officer
D. V. Rama Raju, Purchase Officer
K. C. Saxena, Stores Officer
K. R. Natarajan, Shipping and Purchase Officer
S. K. Dasgupta, Senior Scientific Liaison Officer (Visitors' Services)
A. Lakshminarayana, Scientific Liaison Officer (Visitors' Services)
K. K. Sood, Security Officer
K. K. Vij, Senior Administrative Officer (Delhi Office)
V. Lakshmanan, Assistant Manager (Administration)
N. Suryaprakash Rao, Resident Medical Officer
R. Narsing Reddy, Transport Officer (until September)
G. Vijayakumar, Transport Officer (from October)

International Cooperation

M. Tardieu, Coordinator of Programs, West Africa
K. F. Nwanze, Principal Millet Entomologist and Acting Team Leader, Niger
D. C. Goodman, Administrative Officer, Niger (from November)
K. Anand Kumar, Principal Millet Breeder, Niger
B. B. Singh, Principal Millet Breeder, Niger (Maradi)
L. K. Fussell, Principal Millet Agronomist, Niger
E. J. Guthrie, Principal Millet Pathologist, Niger
J. McIntire, Principal Economist, Niger
M. C. Klaij, Principal Soil and Water Engineer, Niger (from November)
A. Bationo, Soil Scientist (ICRISAT/IFDC), Niger
R. Chase, Soil Scientist (Texas A&M University), Niger
B. Christianson, Soil Scientist (ICRISAT/IFDC), Niger
Maimouna S. Dicko, Animal Nutritionist (ICRISAT/ILCA), Niger
C. M. Pattanayak, Principal Sorghum Breeder and Team Leader, Upper Volta
A. J. Dagenais, Administrative Officer, Upper Volta (until May)
K. V. Ramaiah, Principal Cereal Breeder—*Striga*, Upper Volta
S. N. Lohani, Principal Millet Breeder, Upper Volta
E. R. Perrier, Principal Agronomist, Soil and Water Management, Upper Volta
P. J. Matlon, Principal Production Economist, Upper Volta
Helga Vierich, Principal Social Anthropologist, Upper Volta
W. Stoop, Senior Research Officer (ICRISAT/ISNAR), Upper Volta

S. C. Gupta, Principal Millet Breeder, Senegal
J. F. Scheuring, Principal Cereals Breeder, Mali
P. G. Serafini, Principal Cereals Agronomist, Mali
M. K. O'Neill (International Intern), Mali
S. O. Okiror, Principal Millet Breeder and Team Leader, Nigeria
N. G. P. Rao, Principal Sorghum Breeder, Nigeria (until June)
J. H. MacFarlane, Principal Cereals Entomologist, Nigeria
S. V. R. Shetty, Principal Agronomist, Nigeria (from February)
Brhane Gebrekidan, ICRISAT/SAFGRAD Coordinator for Sorghum and Millet, Eastern and Southern Africa, Kenya
R. P. Jain, Principal Millet Breeder, Sudan
Gebisa Ejeta, Principal Sorghum Breeder, Sudan (until December)
K. R. Bock, Principal Groundnut Pathologist and Team Leader, Malawi (from December)
S. N. Nigam, Principal Groundnut Breeder, Malawi
V. Y. Guiragossian, Principal Sorghum Breeder, Mexico
C. L. Paul, Principal Sorghum Agronomist, Mexico
K. B. Singh, Principal Chickpea Breeder, Syria
M. V. Reddy, Principal Chickpea Pathologist, Syria

Research Programs

Sorghum

L. R. House, Principal Plant Breeder and Leader
S. Z. Mukuru, Principal Plant Breeder
L. K. Mughogho, Principal Plant Pathologist
J. M. Peacock, Principal Plant Physiologist
K. Leuschner, Principal Cereal Entomologist
Bhola Nath Verma, Plant Breeder
D. S. Murty, Plant Breeder
B. L. Agrawal, Plant Breeder
Belum V. S. Reddy, Plant Breeder
M. J. Vasudeva Rao, Plant Breeder (until September)
N. Seetharama, Plant Physiologist
R. K. Maiti, Plant Physiologist (on sabbatic leave)
Suresh Pande, Plant Pathologist
R. Bandopadhyay, Plant Pathologist
S. L. Taneja, Entomologist
H. C. Sharma, Entomologist
S. P. Jaya Kumar, Administrative Officer
Rama (Research Fellow)

Pearl Millet

D. J. Andrews, Principal Plant Breeder and Leader
L. A. Hunt, Principal Plant Breeder (until June)
F. R. Bidinger, Principal Plant Physiologist (on sabbatic leave from May)
R. J. Williams, Principal Plant Pathologist (until February)
S. B. King, Principal Plant Pathologist (from June)
P. J. Dart, Principal Cereal Microbiologist (until September)
K. N. Rai, Plant Breeder
B. S. Talukdar, Plant Breeder
Pheru Singh, Plant Breeder
S. B. Chavan, Plant Breeder
G. Alagarswamy, Plant Physiologist
V. Mahalakshmi, Plant Physiologist
P. Soman, Plant Physiologist
S. D. Singh, Plant Pathologist
R. P. Thakur, Plant Pathologist
S. P. Wani, Microbiologist
K. R. Krishna, Microbiologist
Nirmala Kumar, Administrative Officer
Judith A. Kipe-Nolt (International Intern)

Pulses

Y. L. Nene, Principal Plant Pathologist and Leader (on sabbatic leave until April)
D. G. Faris, Principal Plant Breeder, Pigeonpea
W. Reed, Principal Entomologist
J. B. Smithson, Principal Plant Breeder, Chickpea
J. A. Thompson, Principal Pulse Microbiologist
J. Arihara, Assistant Physiologist, Pulses (Visiting Scientist, TARC)
D. Sharma, Senior Plant Breeder, Pigeonpea
K. C. Jain, Plant Breeder, Pigeonpea (on sabbatic leave from August)
K. B. Saxena, Plant Breeder, Pigeonpea
S. C. Gupta, 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
N. P. Saxena, Plant Physiologist
Y. S. Chauhan, Plant Physiologist
S. S. Lateef, Entomologist
S. Sithanantham, Entomologist
S. P. S. Beniwal, Senior Plant Pathologist
M. P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist (on leave from December)
O. P. Rupela, Microbiologist
J. V. D. K. Kumar Rao, Microbiologist
D. M. Pawar, Agricultural Officer
M. D. Gupta, Senior Research Associate
V. S. Bisht (Research Fellow)
D. R. Dent (International Intern)
J. H. Mareck (International Intern)
S. B. Sharma (Research Fellow)
Harjit Singh (Research Fellow)

Groundnut

R. W. Gibbons, Principal Plant Breeder and Leader (on sabbatic leave from April)
D. McDonald, Principal Plant Pathologist and Leader
D. V. R. Reddy, Principal Plant Virologist (on sabbatic leave from May)
J. H. Williams, Principal Plant Physiologist
J. P. Moss, Principal Cytogeneticist
A. M. Ghanekar, Plant Virologist
L. J. Reddy, Plant Breeder
P. Subrahmanyam, Plant Pathologist
M. J. Vasudeva Rao, Plant Breeder (from October)
V. M. Ramraj, Plant Physiologist (from October)
V. K. Mehan, Plant Pathologist
K. Tanaka, Biochemist (Visiting Scientist, TARC)
M. Saito, Mycologist (Visiting Scientist, TARC)
P. T. C. Nambiar, Microbiologist
P. W. Amin, Entomologist
A. K. Singh, Cytogeneticist
D. C. Sastri, Cytogeneticist
S. L. Dwivedi, Plant Breeder
R. C. Nageswar Rao, Plant Physiologist
A. B. Mohammed, Entomologist
Mohinder Pal, Plant Physiologist (until January)
Y. Bhaskar, Assistant Engineer
P. Subrahmanyam, Administrative Officer
S. N. Azam-Ali, (International Intern)
T. N. Bhavani Shankar (Research Fellow)
M. Dutta (Research Fellow)
B. L. Nolt (International Intern)
Rasheedunisa (Research Fellow)
G. Rajendrudu (Research Fellow)

Farming Systems

S. M. Virmani, Principal Agroclimatologist and Leader
R. W. Willey, Principal Agronomist (on sabbatic leave until September)
C. W. Hong, Principal Soil Scientist (ICRISAT/IFDC)
S. A. El-Swaify, Principal Soil Scientist
G. E. Thierstein, Principal Agricultural Engineer (on sabbatic leave from December)
T. Takenaga, Principal Agricultural Engineer (ICRISAT/JICA) (from August)
J. R. Burford, Principal Soil Chemist
M. V. K. Sivakumar, Principal Agroclimatologist
Y. Nishimura, Principal Assistant Agronomist (ICRISAT/JICA) (until November)
R. Busch, Principal Soil Scientist (ICRISAT/Justus Leibig University)
M. Wurzer, Principal Assistant Soil Scientist (ICRISAT/University of Hamburg)
S. V. R. Shetty, Agronomist (until January)
Piara Singh, Soil Scientist
Sardar Singh, Soil Scientist
T. J. Rego, Soil Scientist
K. P. R. Vittal, Soil Scientist (from June)
K. L. Sahrawat, Soil Chemist (on sabbatic leave from July)
A. K. S. Huda, Agroclimatologist
M. R. Rao, Agronomist (on sabbatic leave)
M. S. Reddy, Agronomist
M. Natarajan, Agronomist
R. C. Sachan, Agricultural Engineer
K. L. Srivastava, Agricultural Engineer
R. K. Bansal, Agricultural Engineer
Prabhakar Pathak, Agricultural Engineer
C. S. Pawar, Entomologist
S. K. Sharma, Senior Research Associate
Siloo Nakra, Executive Assistant (until March)
Surendra Mohan, Administrative Officer
A. A. H. Khan, Senior Research Associate (Engineering)
S. Ramachandran, Senior Secretary
R. T. Hardiman (International Intern)
G. M. Heinrich (International Intern)

Economics

M. von Oppen, Principal Economist and Leader
J. G. Ryan, Principal Economist (until May)
T. S. Walker, Principal Economist (ICRISAT/ADC)
N. S. Jodha, Senior Economist
R. D. Ghodake, Economist
R. P. Singh, Economist
K. N. Murthy, Economist (until September)
R. S. Aiyer, Senior Administrative Officer
K. G. Kshirsagar, Senior Research Associate
K. V. Subba Rao, Senior Research Associate

Support Programs

Biochemistry

R. Jambunathan, Principal Biochemist (on sabbatic leave from July)
Umaid Singh, Biochemist
V. Subramanian, Biochemist (on leave from May)
Santosh Gurtu, Senior Research Associate

Genetic Resources

M. H. Mengesha, Principal Germplasm Botanist and Leader
L. J. G. van der Maesen, Principal Germplasm Botanist
K. E. Prasada Rao, Botanist
S. Appa Rao, Botanist
R. P. S. Pundir, Botanist
P. Remanandan, Botanist
V. Ramanatha Rao, Botanist (on sabbatic leave from June)

Plant Quarantine

B. K. Varma, Chief Plant Quarantine Officer
Upendra Ravi, Senior Research Associate
N. Rajamani, Senior Administrative Officer

Fellowships and Training

D. L. Oswalt, Principal Training Officer
A. S. Murthy, Senior Training Officer
B. Diwakar, Senior Training Officer
T. Nagur, Training Officer
A. Prakash Rao, Training Officer
T. A. Krishnamurthi, Senior Administrative Officer

Information Services

H. L. Thompson, Head
J. B. Wills, Research Editor
Susan D. Feakin, Research Editor (from June)
C. A. Giroux, French Writer/Editor
S. M. Sinha, Assistant Manager (Art and Production)
S. Varma, Editor (on leave from April)
D. R. Mohan Raj, Editor (from February)
N. Raghavan, Editor (from July)
H. S. Duggal, Senior Photographic Supervisor
G. K. Guglani, Art Visualizer
T. R. Kapoor, Composing Supervisor
P. E. Stephen, Printshop Supervisor

Statistics

B. Gilliver, Principal Statistician
Murari Singh, Statistician

Computer Services

J. W. Estes, Computer Services Officer
S. M. Luthra, Assistant Manager (Computer Services)
T. B. R. N. Gupta, Senior Computer Programmer/Analyst
J. Sai Prasad, Computer Programmer/Analyst

Library and Documentation Services

S. Dutta, Manager (Library and Documentation Services)
P. K. Sinha, Senior Documentation Officer
P. S. Jadhav, Library Officer
S. Prasannalakshmi, Library Officer

Housing and Food Services

A. G. Fagot, Manager
S. Mazumdar, Assistant Manager (Food Services)
B. R. Revathi Rao, Assistant Manager (Housing)
D. V. Subba Rao, Assistant Manager (Warehouse)

Physical Plant Services

E. W. Nunn, Station Manager
F. J. Bonhage, Construction Supervising Officer (until July)
P. M. Menon Senior Administrative Officer
Sudhir Rakhra, Chief Engineer (Civil)
D. Subramanyam, Chief Engineer (Electrical)
B. K. Sharma, Senior Engineer (until April)
U. B. Culas, Manager (Workshop)
S. K. V. K. Chari, Senior Engineer (Electronics and Instrumentation)
N. S. S. Prasad, Senior Engineer (from February)
A. R. Das Gupta, Senior Engineer (Communication)
D. C. Raizada, Senior Engineer (Airconditioning)
N. V. Subba Reddy, Horticulture Officer
D. V. S. Verma, Engineer (Machineshop)
R. Thiyagarajan, Engineer (Automobiles)
A. N. Singh, Engineer (Heavy Equipment and Tractors)
S. W. Quadar, Engineer (Office Equipment)
K. Mohan, Engineer (Civil) (from November)

Farm Development and Operations

D. S. Bisht, Farm Manager
S. N. Kapoor, Assistant Manager (Farm Operations)
S. K. Pal, Senior Plant Protection Officer
K. Ravindranath, Senior Engineer (Farm Machinery)
M. Prabhakar Reddy, Agricultural Officer
M. C. Ranganatha Rao, Engineer
K. Santhanam, Senior Administrative Officer