ICRISAT
ANNUAL REPORT 1982

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

Cover: *Groundnut experiments at ICRISAT Center, Patancheru, India.*

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The correct ciation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. Annual Report 1982. Patancheru, A.P., India: ICRISAT.

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 ninth Annual Report covers the 1982 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 we continue reporting the crop improvement programs as interdisciplinary reports on problem areas. 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 on the work reported here are given in individual program publications, which are usually available from the particular research program. Individual program offprints of this Annual Report also are available from the program concerned.

Throughout this Report, the variability of estimates is shown by including standard error (SE); levels of probability are shown by asterisks: * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$. On graphs representing the mean of several observations, the standard error is shown by a line (I).

Contents

ICRISAT's Five Crops

Latin	*Sorghum bicolor* (L.) Moench	*Pennisetum americanum* (L.) Leeke	*Cajanus cajan* (L.)Millsp.	*Cicer arietinum* L.	*Arachis hypogaea* L.
English	Sorghum, durra milo, shallu, kafir corn, Egyptian corn, great millet, Indian millet	Pearl millet bulrush millet, cattail millet, spiked millet	Pigeonpea red gram	Chickpea, Bengal gram, gram, Egyptian pea, Spanish pea, chestnut bean, chick, caravance	Groundnut, peanut
French	Sorgho	Petit mil	Pois d'Angole, pois cajan	Pois chiche	Arachide
Portuguese	Sorgo	Painco perola	Guando, feijao-guando	Grao-de-bico	Amendoim
Spanish	Sorgo, zahina	Mijo perla, rnijo	Gaundul	Garbanzo, garavance	Mani
Hindi	Jowar, jaur	Bajra,	Arhar, tur	Ghana	Mungphali

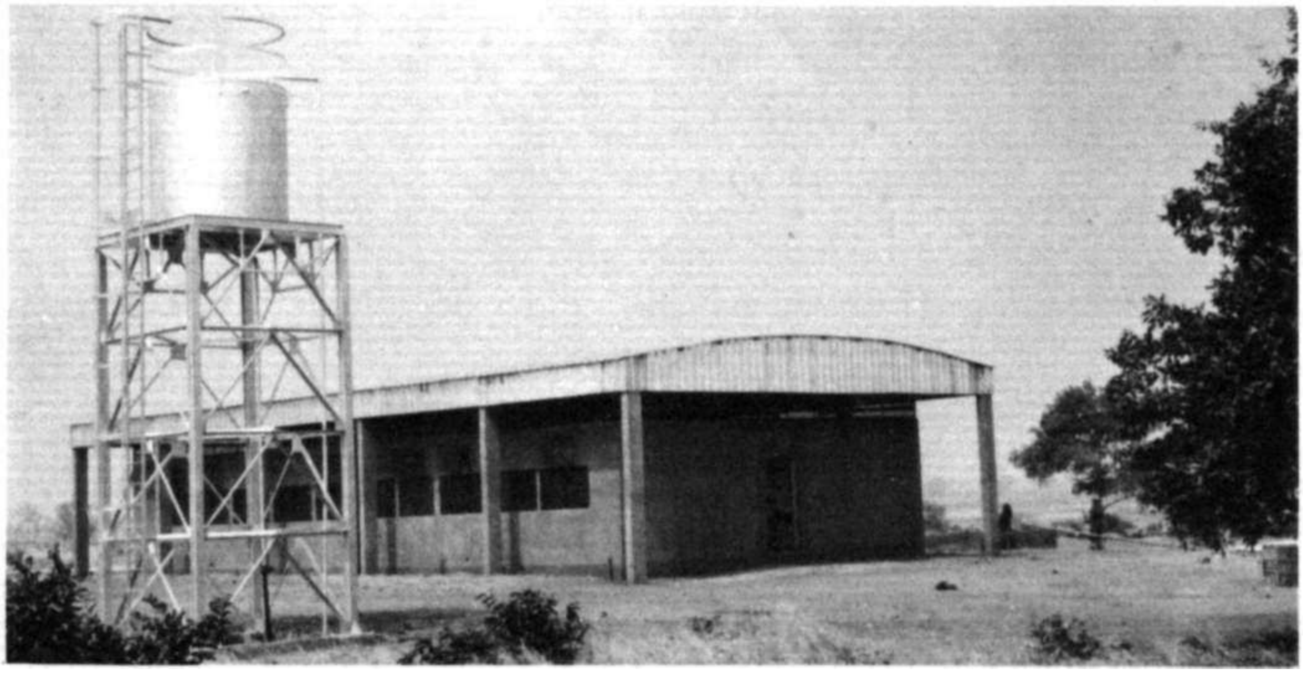
Introduction

For ICRISAT, 1982 was a signal year—the end of a decade of work in India, the beginning of research at the ICRISAT Sahelian Center in West Africa.

At our 10th Anniversary observance at ICRISAT Center on 11 October, we were able to review accomplishments with satisfaction and view the future with confidence. Many of the research results and much of the germplasm we amassed during our first decade can now be transferred with assurance to scientists and farmers in SAT countries.

In Africa, we began operations at the new ICRISAT Sahelian Center in Niger. The 500-hectare experiment farm near Niamey will be the focal point for our work on millets and

The first "office" occupied at the ICRISAT Sahelian Center in Sadore. Niger. Africa; below, the first laboratory facility completed there. Construction of permanent facilities will begin in 1984.



groundnuts, and on farming systems associated with those crops in the southern Sahelian zone of West Africa. It will also serve as the headquarters for our West Africa programs.

Semi-arid Africa offers a major challenge in the decade ahead. Its environment is harsh, its pests are relentless, its plant diseases severe, and food production there has been steadily declining against increasing populations.

Our scientists at the Sahelian Center work in a drought-prone area where 70% of the annual rainfall occurs within 5 weeks, soil temperatures can reach 60° C (140° F), and the soil is 92% sand.

In 1982 we also began our response to the request of nine Heads of State in the Southern African Development Coordination Conference (SADCC) for help in increasing their food supplies. Our most recent project was establishing a regional groundnut improvement program for southern and eastern Africa in cooperation with the Government of Malawi. Our groundnut breeder arrived at the Chidetze Agricultural Research Station in Lilongwe in September and began plantings in November of ICRISAT materials including 2000 breeding lines, breeding populations, germplasm lines, and elite parents. A pathologist will join him in 1983.

The team will conduct trials throughout southern and eastern Africa to produce groundnuts with multiple disease resistance, high yield, good food quality, earliness, and increased seed size. Their results should apply to all southern African countries and should be especially valuable in Tanzania, Mozambique, Zimbabwe, and Zambia, as well as Malawi.

ICRISAT groundnut scientists study diseased plants in a farmer's field in Malawi. The new regional cooperative groundnut program established in Malawi will conduct trials to improve disease resistance throughout southern and eastern Africa.

One of four sorghum varieties from the ICRISAT population breeding program being marketed in China after 2 years of selection and evaluation there.

In addition to the regional cooperative groundnut program based in Malawi, we hope to establish similar regional cooperative programs for sorghum, pearl millet, and dryland farming systems in southern Africa. We posted a sorghum and pearl millet coordinator for eastern and southern Africa at Nairobi in 1982 in cooperation with SAFGRAD.

Our efforts in Latin America resulted in the release in 1982 of three sorghum varieties by Mexico's national agricultural institute, release of two varieties in El Salvador, a 50-hectare planting for seed production in Venezuela, an ICRISAT variety going into production in Nicaragua, several ICRISAT food-type sorghums being increased in large plots in Guatemala, and eight ICRISAT varieties being increased on farmers' fields in Haiti.

ICRISAT sorghums are also doing well in China. Four varieties from our population breeding program entered the market in China after 2 years of local selection and evaluation.

In India, which tests new varieties for up to 6 years before releasing them to farmers, our elite sorghum variety SPV 351 moved to within one step of release and several other lines advanced through earlier testing stages.

Our first pearl millet variety to be released in India, WC-C75, which resists downy mildew, went into commercial seed production this year. We shipped nearly 1000 kg of WC-C75 to agricultural departments in various Indian states, and 340 kg went to agencies that multiply seed. We supplied 750 kg of another variety, ICMS 7703, to the All-India Coordinated Millet Improvement Project for its final year of extensive on-farm testing, and another 400 kg to state agricultural departments.

Two ICRISAT millet synthetics bred in Senegal averaged 22% higher yields in 3-year tests than Souna III, the local standard variety previously released for its superiority. The two synthetics advanced to prerelease, on-farm evaluation.

Our program at the University of Queensland developed a system of using high-yielding, early-maturing pigeonpeas for improved production in Australia. A similar improved production system, accepted in Fiji, is expected to make that country self-sufficient in pigeonpea, and indicates the potential use of such systems in other developing countries.

Work at the University of Queensland has provided sources of male sterility, photoperiod-insensitive lines, and fast-ratooning lines for the improved production system. Genetic material from the program has been distributed to many parts of the world.

In cooperation with the Queensland Graingrowers Association, seed of QPL-96 pigeonpea was increased for release under the name 'Hunt' to growers in Australia in 1982. Hunt is from the cross Prabhat x Baigani in the ICRISAT breeding program in India.

Although ICRISAT funding for the cooperative work at the University of Queensland ended in November 1982, the program will continue under alternate funding.

Seed hags of WC-C75, ICRISAT's first pearl millet variety released in India. Commercial seed production started this year in Maharashtra.

The pigeonpea cultivar 'Hunt'. released to Australian growers from a eross in the ICRISAT breeding program in India, is high yielding and relatively insensitive to photoperiod.

A chickpea developed jointly by ICARDA and ICRISAT to resist ascochyta blight, ILC 482, was released in 1982 for winter sowing and general cultivation in the drier areas of Syria. Another chickpea, ILC 484, is being multiplied for large-scale trials in Jordan.

We confirmed good resistance to *Heliothis armigera* in chickpea, and to a lesser extent in pigeonpea, which we are now transferring to better adapted material.

Our program of incorporating resistant genes from wild groundnut species progressed in 1982 as we produced pegs and pods from crosses previously considered incompatible. We also produced hybrids with wild species newly introduced to ICRISAT, and found that crossability, which is low in early generations, usually increased with successive backcrosses.

During the 1982 rainy season, when rust and leaf spot attacked other groundnut varieties, eight ICRISAT genotypes that resist rust and leaf spot yielded $2^{1}/_{2}$ times as much (1000 vs 400 kg/ha) as three released varieties. At Anantapur, India, during the 1982 rainy season, we had several drought-resistant genotypes yield more than 1000 kg/ha, compared with 500 to 800 kg/ha by released varieties.

Agricultural officials from Indian states view a traditional farm at Taddanpally. Andhra Pradesh. During the year. five teams of senior officers visited ICRISAT, and on-farm tests spread to eight locations in Jour states. Below, interrow cultivation in progress at Gulharga. Karnataka, one of the sites.

We distributed 4187 populations and breeding lines of groundnut to 31 countries during 1982.

In India our efforts to transfer technology to deep black soils in areas with assured rainfall expanded dramatically.

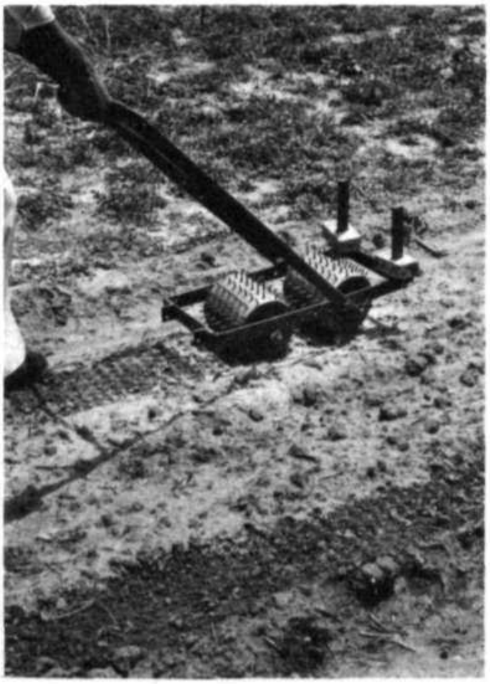
Experiences in 1981/82 with 14 farmers in Taddanpally village, about 42 km from ICRISAT Center, were gratifying to us and to those at Indian research institutions and the Central Government and Andhra Pradesh Departments of Agriculture with whom we initiated the farmers' test of Vertisol management on farms in 1980.

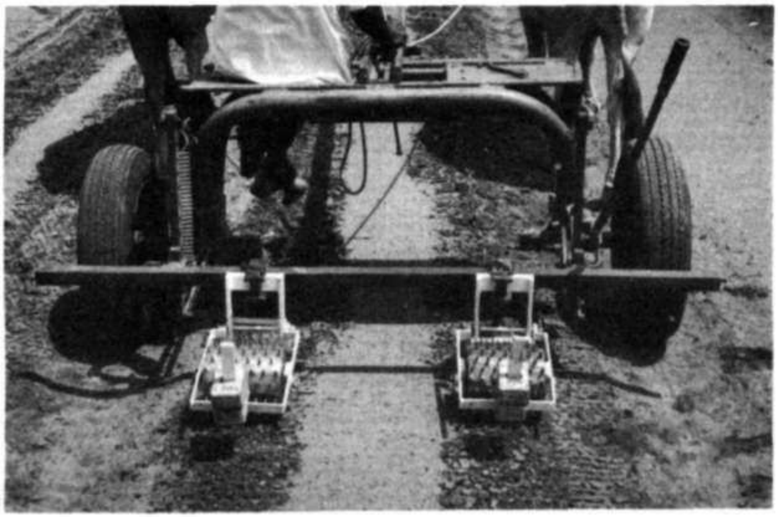
The nine crop combinations that the 14 farmers chose far exceeded production of other farms in the vicinity. While returns from other farms averaged Rs. 1625 per hectare, those for the 14 cooperating Taddanpally farmers averaged Rs.3059. The improved systems required an extra Rs.588 per hectare, but the extra income was Rs. 1434 per hectare. That is a 244% return on the added expense.

Farmers in Sultanpur, a neighboring village, asked to participate in the project in 1982/83. The 17 farmers there will be trying various crop combinations that they choose on a total of 35.2 hectares. We are also working closely with scientists and extension officers in three other states of India in on-farm verification trials that should further speed the transfer of this technology to farmers.

The 1982 results confirm that many deep Vertisol watersheds, now left fallow in India during the rainy season, should be producing both rainy and postrainy season crops. As the ICRISAT-developed, improved farming system is adapted to various areas, it can be applied to several million hectares of deep Vertisol watersheds in India—to the financial advantage of farmers and their communities through the increased food produced.

We made good progress in 1982 in improving the machinery and equipment that can be used by small farmers.





To break the crusts that reduce seedling emergence, ICRISAT engineers developed two models of a rolling crust breaker, one for hand operation and one for an animal-drawn wheeled tool carrier.

Among more than 1500 farmers who visited ICRISAT Center on 3 October were 67 from the Tata Agricultural and Rural Training Centre for the Blind who "see feelingly."

To break the crust that reduces seedling emergence, we developed and tested two models of a rolling crust breaker, one for hand operation; the other to fit an animal-drawn wheeled tool carrier. Emergence was 96% when the crust was broken in our tests with seedling sorghum IS 8129; 38% where it was not. The crust breaker made an even more important difference with millet emergence. Only 1 of 10 millet genotypes exceeded 4% emergence under a crust, compared with 23 to 55% with the crust broken.

We also designed a furrow opener that does not clog easily in wet soil, requires relatively low draft, and places seed and fertilizer 10 to 12 cm deep, acceptably separated.

Our long-term training program attracted 126 scientists and technical assistants from 35 countries; scientists from 4 countries did postdoctoral work; 91 persons from 29 countries took part in the 6-month, in-service training program; 11 countries sent 32 students to do Ph.D. and M.Sc thesis research; and 7 young scientists from 4 countries took specialized skill development training as in-service fellows in a recently initiated program.

As part of the ICRISAT program in Mexico, 15 Latin American scientists in sorghum improvement completed training in 1982, and in Mali we helped several thesis students who then were employed by the Malian government as research scientists.

ICRISAT's two-way exchange of knowledge with farmers lets them help us as we help them. More than 1500 farmers visited ICRISAT Center 3 October for Farmers' Day during our 10th Anniversary. Among them were 67 from the Tata Agricultural and Rural Training Centre for the Blind. The blind farmers who are trained in 2 years to be self sufficient on 1.5 to 2.5 hectares in their villages, examined machinery that ICRISAT engineers have designed for Indian farms, as well as the growing crops, by touch.

Even though insects, diseases, and drought likely will always pose problems for farmers in the semi-arid tropics, we are in a much better position to deal with them now than 10 years ago.

During the decade, for example, ICRISAT sorghum scientists developed varieties, hybrids, breeding lines, and other material that resist armyworm, anthracnose, charcoal rot, drought, downy mildew, head bugs, leaf rusts, shoot flies, sorghum midge, and stem borers. Similar progress has been made with all our mandate crops.

The base is well established for the work that lies ahead.

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 listed with experiments in the program reports.

ICRISAT Center

The Institute is located at 18°N, 78 E on 1394 hectares near Patancheru village, 25 km northwest of Hyderabad on the Bombay Highway. The experimental farm includes two major soil types found in the semi-arid tropics: Alfisols (red soils), which are light and drought prone, and Vertisols (black soils), which have great water-holding capacity. The availability of both soil types provides an opportunity to conduct experimental work on our five mandate crops under conditions representative of many 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. The cropping schedule generally followed at ICRISAT Center is shown in Figure 1.

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.

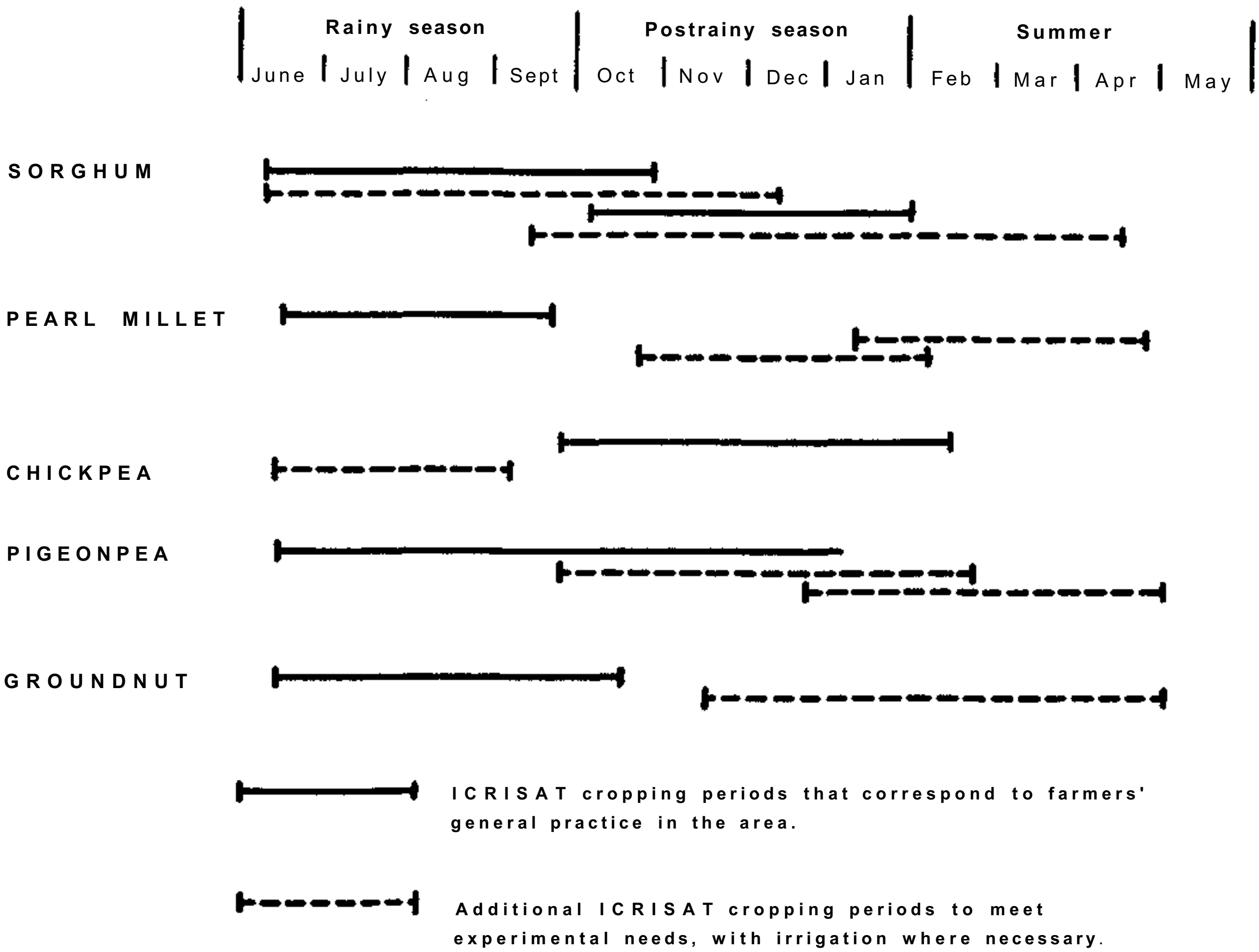


Figure 1. ICRISAT Center's cropping schedule.

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. Our cooperative work at Hissar was started 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. Likewise the need for extending the work on sorghum to screen for diseases and pests was met at Dharwar (an especially good site for sorghum downy mildew screening), and Bhavanisagar, which also provides another test environment for pearl millet at a latitude (i.e., daylength analog) similar to the West African millet belt. Our research station at Gwalior provides us with an effective screening site in the region where most of India's late-maturing pigeonpea crop is grown, and it provides an alternative site for selecting chickpea. Anantapur, our most recently acquired site (1980), is used during the rainy season to screen pearl millet, sorghum, and groundnut for drought.

The Weather

ICRISAT Center. Rainfall received during the 1982 rainy season (June to October) was 656 mm, against a normal of 690 mm for this period. Monthly rainfall and temperature data from January to December 1982 are presented in Table 1.

Anantapur. Of the 590 mm mean annual rainfall, over 80% is spread over a long rainy season extending from May to October (Table 2). Rainfall in the 1982 rainy season was 340 mm, 42% below normal.

Bhavanisagar. Normal rainfall data are not available for this station. Rainfall received during May to December 1982 was 362 mm (Table 3).

Dharwar. Data on rainfall and temperature recorded at Dharwar are given in Table 4. Rainfall received during May to October 1982 was 679 mm, 3% below the normal of 697 mm for this period.

Gwalior. As shown in Table 5, rainfall received during the 1982 rainy season (June to October) was 853 mm, just above the normal of 843 mm. Over the year, total rainfall was 7% above normal.

Hissar. At Hissar, rainfall receded early in August during the 1982 season (Table 6). Against a normal rainfall of 96 mm during September and October, no rainfall occurred during these months. Over the year, however, rainfall was above normal, due to rains during March to June.

ICRISAT Sahelian Center. Against a normal rainfall of 588 mm during June to October at Niamey (Table 7), rainfall during 1982 was only 372 mm (37% below normal). Annual rainfall, too, was 37% below normal. Particularly damaging to crop growth and establishment was the poor rainfall in July, 76% below normal.

Table 1. Rainfall and temperature at ICRISAT Center, 1982.

	Rainfall (mm)		Temperature (°C)			
			Normal[2]		1982	
	Normal[1]	1982	Max	Min	Max	Min
January	6	0	29	15	29	16
February	11	0	31	17	32	18
March	13	0	35	20	35	21
April	24	34	37	24	37	22
May	27	38	39	26	37	24
June	115	193	34	24	34	24
July	171	155	30	22	31	23
August	156	69	29	22	30	23
September	181	180	30	22	30	22
October	67	59	30	20	30	20
November	23	12	29	16	29	17
December	6	0	28	13	28	13

1. Based on 1901-70 rainfall data.
2. Based on 1931-60 temperature data.

Table 2. Rainfall and temperature at Anantapur, 1982.

	Rainfall (mm)		Temperature (°C)			
			Normal[2]		1982	
	Normal[1]	1982	Max	Min	Max	Min
January	7	0	30.4	17.3	29.3	17.7
February	2	0	33.4	18.6	33.5	20.6
March	5	0	36.8	21.6	36.3	23.1
April	24	2	38.4	25.7	37.8	26.3
May	57	106	38.1	25.8	37.7	26.7
June	49	85	34.7	24.7	34.5	25.5
July	66	45	32.4	23.7	32.9	24.5
August	74	2	32.4	23.5	32.8	24.6
September	138	100	32.5	23.1	32.2	25.2
October	126	0	31.4	22.5	32.7	22.7
November	36	0	30.0	19.4	29.5	20.1
December	6	0	29.1	17.2	28.7	16.9

1. Based on 1910-69 rainfall data.
2. Based on 1931-60 temperature data.

Table 3. Rainfall and temperature at Bhavanisagar, 1982.

Month	Rainfall (mm)	Temperature (°C) Max	Min
January	0	30.0	20.2
February	0	32.9	20.5
March	0	35.0	24.0
April	26	36.0	26.6
May	34	35.8	26.8
June	11	34.0	26.8
July	8	34.1	26.4
August	4	33.4	26.5
September	90	34.0	26.0
October	38	32.8	24.4
November	173	30.3	23.4
December	4	29.6	19.9

Table 4. Rainfall and temperature at Dharwar, 1982.

	Rainfall (mm)		Temperature (°C)			
			Normal[2]		1982	
	Normal[1]	1982	Max	Min	Max	Min
January	2	0	29.3	14.3	29.8	13.6
February	2	0	32.1	16.3	33.2	16.4
March	9	0	34.8	18.8	35.6	18.2
April	48	26	36.3	20.8	36.9	19.6
May	75	165	34.9	21.1	34.9	20.2
June	96	105	29.1	20.8	29.3	20.1
July	175	121	26.5	20.5	27.3	19.7
August	122	163	26.4	20.1	25.8	19.8
September	103	30	28.2	19.6	28.3	19.0
October	126	95	29.7	19.1	30.9	18.7
November	48	1	28.6	17.0	28.6	16.5
December	12	0	28.4	13.7	28.5	12.2

1. Based on data for the period 1901-50.
2. Based on data for the period 1972-81.

Table *5*. Rainfall and temperature at Gwalior, 1982.

	Rainfall		Temperature (°C)			
			Normal[1]		1982	
	Normal[1]	1982	Max	Min	Max	Min
January	18	19	23.2	7.5	22.2	8.9
February	8	7	26.6	10.0	22.7	10.7
March	8	19	32.9	16.0	28.5	13.7
April	3	3	38.5	22.3	36.4	20.9
May	9	11	42.6	28.0	38.4	24.9
June	83	53	40.8	30.2	40.4	27.8
July	274	207	34.1	26.6	37.0	27.6
August	259	544	31.9	25.4	31.7	24.6
September	192	40	32.4	24.4	33.6	22.7
October	35	10	33.2	18.0	34.5	19.3
November	2	37	29.4	10.5	28.1	14.0
December	8	16	24.8	7.2	24.0	8.2

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

Table 6. Rainfall and temperature at Hissar, 1982.

	Rainfall (mm)		Temperature (°C)			
			Normal[1]		1982	
	Normal[1]	1982	Max	Min	Max	Min
January	19	9	21.7	5.5	20.0	5.8
February	15	18	25.0	8.1	19.4	7.2
March	17	42	30.7	13.3	24.2	10.4
April	6	54	37.0	19.0	33.5	16.9
May	11	78	41.6	24.6	35.6	21.2
June	34	48	41.3	27.7	40.0	26.6
July	122	106	37.3	27.3	37.7	26.7
August	114	101	35.5	26.1	34.9	25.7
September	81	0	35.7	23.9	37.0	22.3
October	15	0	34.6	17.4	33.6	18.1
November	8	0	29.6	9.8	28.3	11.7
December	5	8.5	24.1	6.0	22.5	6.0

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

Table 7. Rainfall and temperature at ICRISAT Sahelian Center, Niamey, Niger, Jan-Dec 1982.

	Rainfall (mm)		Temperature (°C)			
			Normal[1]		1982	
Month	Normal[1]	1982	Max	Min	Max	Min
January	0	-	34	14	32.0	14.5
February	0	-	37	17	34.3	19.2
March	1	3	41	21	38.0	23.8
April	3	-	42	25	41.5	26.8
May	46	24	41	27	40.1	27.7
June	79	55	38	25	37.8	26.4
July	181	43	34	23	35.8	24.8
August	206	194	32	23	32.6	22.8
September	101	69	34	23	36.1	24.6
October	21	11	38	23	37.7	23.3
November	0	0	38	18	33.6	17.4
December	0	0	34	15	32.9	17.9

1. Based on 1931-60 data.

GENETIC RESOURCES UNIT

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GENETIC RESOURCES UNIT

ICRISAT's germplasm collections, managed by the Genetic Resources Unit, are the present and future foundations for improving the five mandate crops. Further progress can now be reported on ways to acquire more of the genetic resources not collected but available in traditional farming. Collecting and conserving are major goals, and much emphasis is laid on evaluating, documenting, and supplying seed to help crop improvement programs worldwide.

Genetic resources of sorghum, pearl millet, pigeonpea, chickpea, groundnut, and minor millets are threatened by genetic erosion, regional droughts, replacement by new cultivars and crops, and habitat destruction causing wild relatives to disappear. Germplasm from tracts under irrigation development schemes also must be saved for use in rainfed areas.

By guarding the germplasm of the major food and cash crops of mainly small farmers in the semi-arid tropics, ICRISAT's Genetic Resources Unit plays an important role in the worldwide network of genetic resources institutions, promoted by FAO, UNDP, UNEP, CGIAR, international and national institutes, foundations, government agencies and universities. Time, accessibility, and budget constraints pose problems, but in most cases we have been able to carry out plans for collecting in priority areas.

By the end of 1982, 74 798 germplasm accessions of our mandate crops and the six minor millets had been assembled (Table 1). Major collections were carried out during 1982 in Brazil, Ethiopia, Kenya, Rwanda, Burundi, Nigeria, South Africa, Zimbabwe, and some areas of India (Jammu, the Palni and Cardamom Hills, northern Bengal and Sikkim, and northern Uttar Pradesh).

Our own collection efforts and material received from various donors added 3172 new accessions during 1982. Although we have reduced the number of geographical gaps in our collections, many areas are still high on our priority list.

By the crops indicated, the following areas urgently need to be explored for collections either in part or as a whole, and for cultivated genotypes, wild relative species, or both:

Sorghum : Angola, southern Sudan, Central African Republic, Uganda, Chad, Ivory Coast, Sierra Leone, Mozambique, Nepal, Ghana, Morocco, North and South Yemen, northern Syria, southern Turkey, parts of India, China.

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

Pigeonpea : Malawi, Zaire, Burma, Philippines, Uganda, Caribbean Islands, southeastern China, Southeast Asia, Australia.

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

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

Many other areas are also of interest for future collections. The move to the new Genetic Resources Laboratory (in the Phase II buildings) in December provided the Genetic Resources Unit proper facilities to better serve the scientific community. The new, large, short-term storage relieves space in the crop-work area for bulk storage. The new medium- and long-term storage modules will soon be ready for use. The medium-term storage facility was made possible through a financial grant from the Asian Development Bank.

The new laboratory (equipped with seed germinators, growth chambers, microscopes for cytological verification of cultivated and wild germplasm, and seed handling and cleaning equipment) will facilitate work hitherto scattered in different parts of the Institute. A spacious herbarium room will store the precious

Table 1. Germplasm collection status at ICRISAT as of 31 December 1982.

	Number of accessions				
Location	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
AFRICA					
Algeria	0	0	0	18	0
Angola	29	0	0	0	8
Benin	4	17	0	0	10
Botswana	190	45	0	0	1
Cameroon	1835	171	0	0	2
Central African Rep.	39	58	0	0	2
Chad	138	62	0	0	10
Comoros	0	0	0	0	1
Congo	0	0	0	0	5
Egypt	22	0	0	51	10
Equatorial Guinea	0	0	0	0	10
Ethiopia	4242	0	0	160	0
Gambia	57	17	0	0	22
Ghana	64	256	2	0	34
Guinea	0	0	0	0	17
Ivory Coast	1	0	0	0	61
Kenya	761	47	64	0	34
Lesotho	8	0	0	0	0
Liberia	0	0	0	0	12
Malagasy Republic	1	0	1	0	31
Malawi	437	245	20	3	133
Mali	111	873	0	0	22
Mauritania	0	1	0	0	0
Mauritius	0	0	0	0	17
Morocco	0	0	0	53	16
Mozambique	42	28	0	0	126
Namibia	1	0	0	0	0
Niger	408	1032	0	0	5
Nigeria	1173	610	27	3	238
Senegal	237	306	10	0	209
Sierra Leone	3	0	0	0	16
Somalia	125	3	0	0	6
South Africa	726	16	1	0	107
Sudan	2256	274	0	5	165
Swaziland	19	0	0	0	6
Tanzania	432	138	167	2	233
Togo	.0	58	0	0	9
Tunisia	0	0	0	30	0
Uganda	612	48	0	0	134
Upper Volta	248	34	0	0	49

Continued.

Table 1. *Continued.*

Location	Number of accessions				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
Zaire	24	0	0	0	83
Zambia	210	77	20	0	159
Zimbabwe	186	52	0	0	420
ASIA					
Afghanistan	6	0	0	674	0
Bangladesh	9	0	57	32	0
Burma	8	0	64	12	19
Cambodia	0	0	0	0	1
China	68	0	0	0	174
Cyprus	1	0	0	22	5
India	4138	10762	9025	5489	1996
Indonesia	32	0	4	0	120
Iran	7	0	0	4093	10
Iraq	4	0	0	18	0
Israel	22	0	0	48	40
Japan	111	0	0	0	44
Jordan	0	0	0	24	0
Lebanon	360	71	0	18	0
Malaysia	0	0	0	0	59
Nepal	8	0	116	70	0
Pakistan	29	5	15	148	0
Philippines	5	0	37	0	19
Saudi Arabia	1	0	0	0	0
South Korea	2	0	0	0	0
Sri Lanka	25	0	70	3	15
Syria	4	0	0	12	1
Taiwan	13	0	3	0	41
Thailand	5	0	20	0	8
Turkey	51	0	0	436	5
Yemen AR	216	0	0	0	1
Yemen PDR	1	0	0	0	0
EUROPE					
Belgium	1	0	0	0	3
Bulgaria	0	0	0	5	2
Czechoslavakia	0	0	0	8	0
France	5	0	20	1	1
German DR	4	0	0	1	0

Continued.

Table 1. *Continued.*

	Number of accessions				
Location	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
Greece	1	0	0	24	4
Hungary	26	0	0	4	1
Italy	8	0	5	18	0
Portugal	6	0	0	4	1
Spain	3	0	0	77	1
UK	1	0	0	0	0
USSR	69	12	2	93	63
Yugoslavia	0	0	0	2	0
THE AMERICAS					
Argentina	16	0	0	0	274
Barbados	0	0	0	0	4
Bolivia	0	0	0	0	109
Brazil	0	0	7	0	395
Chile	0	0	0	136	12
Colombia	0	0	5	1	0
Costa Rica	0	0	0	0	1
Cuba	3	0	0	0	20
Dominican Rep.	0	0	6	0	0
Ecuador	0	0	0	0	2
El Salvador	1	0	0	0	0
French W. Indies	0	0	4	0	5
Guatemala	6	0	0	0	0
Guyana	0	0	7	0	0
Honduras	1	0	0	0	4
Jamaica	0	0	18	0	1
Mexico	234	7	2	359	6
Nicaragua	1	0	0	0	0
Paraguay	0	0	0	0	139
Peru	0	0	5	2	203
Puerto Rico	0	0	45	0	4
Trinidad	3	0	22	0	3
Uruguay	1	0	0	0	29
USA	1879	48	3	108	1548
Venezuela	1	0	15	0	12
AUSTRALIA AND OCEANIA					
Australia	28	4	47	0	52
Fiji	0	0	0	0	2

Continued.

Table 1. *Continued.*

Location	Number of accessions				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
New Guinea	1	0	0	0	0
UNKNOWN	397	11	0	235	2330
Total	22466	15388	9936	12502	10211

Minor millets collection at ICRISAT

Species	No. of accessions
Eleusine coracana (finger millet)	1422
Setaria italica (foxtail millet)	1196
Panicum miliaceum (proso millet)	735
Panicum sumatrense (little millet)	243
Echinochloa crusgalli (barnyard millet)	393
Paspalum scrobiculatum (kodo millet)	306
Total	4295

reference material of several hundred species, gathered during many trips, to serve as a permanent reference. Companion species and weeds are filed to assist in identification and verification. The new building enhances preservation of the samples under controlled conditions.

The major portion of the germplasm is now stored at 4 to 5°C and 30 to 40% relative humidity. The medium-term stores, equipped with compactor shelves, already have relieved us from frequent rejuvenation of germplasm. Our initial germination tests showed that viability of fresh seeds placed in the medium-term cold stores for 2 years remains very good (94% average for groundnut cultivars).

Multilocational testing continued in Ethiopia for sorghum, and at Hissar for chickpea, but a combined attack of *Botrytis* - *Ascochyta* wiped out all but 20 chickpea accessions at Hissar. The survivors will be evaluated to determine if they are really resistant.

In collaboration with scientists in other disciplines, we will continue to screen new germplasm for various attributes. Evaluation of our germplasm at, or near, their original habitats will be increased in the immediate future. Some preliminary, promising discussions have been made with Kenyan and Cameroon scientists to launch such evaluations jointly in their countries.

Table 2 shows the number of samples distributed in 1982 to scientists in and outside India.

Table 2. Germplasm distribution in 1982.

Crop	Samples distributed[1]			
	India	Other countries	Total samples	Other countries[2] (no.)
Sorghum	1430	12785	14215	27
Pearl millet	569	429	998	12
Pigeonpea	1326	569	1895	22
Chickpea	4801	1038	5839	19
Groundnut	2208	1423	3631	18
Minor millets	2080	901	2981	7

1. Figures do not include more than 40 000 samples of germplasm shared with 1CRISAT scientists.
2. Most of these countries also provided germplasm to ICRISAT (see Table 1).

The numbers shared in the Institute are even larger. The importance of the seed supply service is well understood, and the most useful germplasm available is sent. Seed supply abroad is channeled through the Government of India quarantine authorities, who inspect and clear the seeds.

Documentation was furthered this year by transcribing existing data on to the new computer, which will make data retrieval (for selection and analysis) possible. More concerted efforts will now be made to document and computerize germplasm passport and evaluation data for all our crops.

Sorghum Germplasm

Efforts to assemble sorghum germplasm from new areas continued, and 1202 new accessions were added to the existing collection of 21 264, for a total of 22,466. The new additions were assembled from 16 countries—by collection expeditions and correspondence.

Collection expeditions were organized in the two high altitude central African countries, Rwanda and Burundi, where sorghum had not been collected before. A new range of variation in the collection was noticed for panicle type and grain color. Some types described by Snowden as S. *nigricans* were recovered. Other expeditions were organized during the year in Zimbabwe and Kenya.

A total of 427 accessions—from Nigeria (193), Zambia (85), Ghana (79), and Sudan (70)—were planted in the Postentry Quarantine Isolation Area (PEQIA) for inspection and release. Pending clearance by Indian plant quarantine authorities are 2270 accessions from ORSTOM: West Africa (1240), Mali (369), Ethiopia (260), Rwanda (170), Burundi (105), Kenya (95), and Zimbabwe (31).

To meet the increasing requests for seed, we rejuvenated 4609 accessions during the postrainy season by using the technique of selfing, and 118 male-sterile lines were maintained by hand pollination. All accessions are now conserved in medium-term cold storage.

Sorghum germplasm, collected for the first time from Burundi in eastern Africa, has provided a new range of panicle types and grain color to ICRISAT's gene hank.

Also during the postrainy and rainy seasons, 4675 newly assembled accessions were characterized and evaluated at ICRISAT for morpho-agronomic characters.

Collaborating with scientists of the Sorghum Program, we continued to screen germplasm for insect and disease resistance: 15 036 accessions during the year for resistance to midge, earhead bug, stem borer, shoot fly, anthracnose, downy mildew, and grain molds. For the first time, wild relatives of sorghum were screened for response to downy mildew by the Sorghum Pathology Unit and two accessions from 5 . *arundinaceum* and *S. sudanense* gave an immune reaction at ICRISAT Center.

A base collection consisting of about a thousand accessions was selected from the World Collection and stratified taxonomically and geographically, based on their ecological adaptation at Patancheru. The material is already being used by sorghum scientists of ICRISAT (to screen for resistance to midge and head bug, and for grain quality), by Indian institutions, and by scientists of Japan, Uganda, Upper Volta, and Mali in their improvement programs.

Internationally acceptable descriptors were standardized and published in collaboration with IBPGR. Adding to the data already compu-

This photoperiod-insensitive zera-zera sorghum was convened at ICRISAT Center from the photoperiod-sensitive landrace collected in Gambela, Ethiopia. The conversion gives us new agronomic characteristics to use in breeding programs.

terized, evaluation data for important descriptors with passport information from IS 10 051 onwards have been tabulated to be computerized.

For an effective and easy flow of tropical germplasm into various sorghum improvement programs around the world, we initiated an introgression and conversion project in 1979. Now we are converting zera-zera land races from Sudan and Ethiopia, which are highly prized for their superior agronomic characteristics, but have restricted utility because they are photoperiod sensitive and much too tall. The converted F_3 populations grown at ICRISAT Center in 1982 produced promising segregants, which combine in zera-zera heads such other desirable traits as improved grain quality and quantity, photoperiodic insensitivity, and shorter plant height. They were selected by ICRISAT breeders, in-service trainees, AICSIP breeders, and breeders of private seed companies. The nearly 3000 selections will be made into bulks for growing and further selection by interested breeders.

Pearl Millet Germplasm

A germplasm collection mission to Zimbabwe, jointly launched by ICRISAT and IBPGR in collaboration with the Department of Agriculture of Zimbabwe, yielded 37 samples of pearl millet. Two wild species of *Pennisetum* were collected from Burundi. Millet physiologists collected 17 samples from Rajasthan, which include very primitive landraces with shattering spikelets. From the hilly areas of Andhra Pradesh, 18 more samples were collected. The millet breeder from Mali collected 167 samples. The IBPGR collection from Nigeria was received after multiplication by selfing in Pune. Of the 132 samples received, seed was obtained from 118, so our collection now has 15 388 samples.

Of the 1280 samples from 10 countries sown in PEQIA, 931 were released after quarantine inspection; the rest did not germinate. Remnant seeds of 242 accessions were again sown in quarantine. In addition, 876 samples—from Sudan (376), USA (218), Mali (167), Senegal (50), Zimbabwe (36), Kenya (15), Ghana (12), and Burundi (2)—were sown for quarantine inspection and seed increase.

During the postrainy season, 2196 accessions were rejuvenated and processed for storage to replenish the seed quantity or restore normal viability.

Besides the 931 accessions released from quarantine, 148 samples collected from Maharashtra and 118 samples from Nigeria were evaluated during the rainy season for various morphological and agronomical characters.

In total 1255 selected germplasm lines were classified for male sterility maintaining and restoring ability on 5141A. The search for new characters and new sources was intensified. From the germplasm grow-outs, 35 new dwarf stocks were identified, as well as 125 from the breeders' plots. The true-breeding dwarf stocks were crossed to the known dwarf stock d2. When the F_1 was dwarf, it was assumed to he allelic to d2. When the F_1 from such a cross was tall, it was assumed to be nonallelic to d2. Such a genetic analysis indicated at least three dwarf stocks that are nonallelic to d2. Observations on these new dwarf stocks are continuing.

Glossy leaves, a trait not previously reported, were identified after screening more than 6000 accessions. The glossy trait, identifiable in the earliest seedling stage, was best expressed around 14 days after plants emerged. Preliminary observations show that the glossy leaf character is recessive and controlled by a single gene.

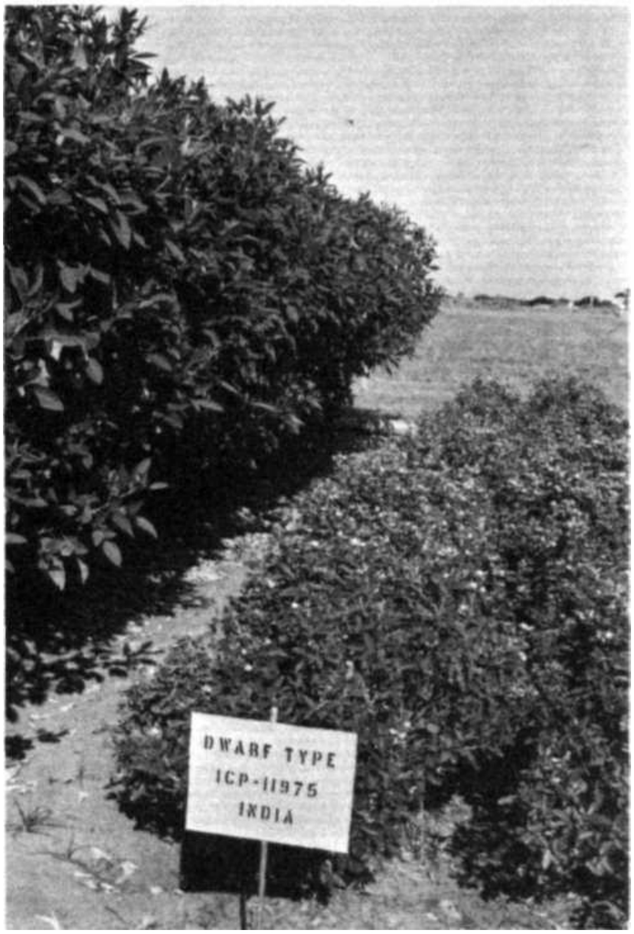
Careful examination of anthers and seed-set after selfing helped us identify several male-sterile lines, most of which are genetic. We later identified four morphologically distinct male-sterile lines and their maintainers, some of which we are evaluating jointly with the breeders.

By mutagenic treatment of tall, photoperiod-sensitive, long-duration West African types, we identified some very interesting early-maturing dwarf mutants, 37 of which were selected by breeders. Several chlorophyll mutants were isolated and characterized, and their mode of inheritance was studied.

In collaboration with scientists in other disciplines, we screened 1227 new germplasm lines for resistance to downy mildew and rust (784), ergot (123), drought (101), insects (212), and grain quality (7).

For meaningful comparisons of data from different locations and recorders, 1CR1SAT and IBPGR jointly published Descriptors for Pearl Millet.

Evaluation data of more than 4000 accessions were tabulated for the computer.



Tall and dwarf types of pigeonpea germplasm, grown side by side at ICRISAT Center, show the diversity of plant heights available in germplasm for plant breeders around the world.

Pigeonpea Germplasm

Collection from priority areas continued, and a systematic germplasm collection launched in Kenya secured 282 representative landraces of pigeonpea. This material includes new records for seed weight (26.92 g/100 seed) and a new green seedcoat color. Adding more large-seeded perennials to the World Collection, many of which seem to have high yield potential and drought tolerance, has substantially broadened the genetic base for the vegetable-type pigeonpeas needed in such areas as East Africa and the Caribbean Islands. To secure more wild species, we organized pointed collections in the Western Ghats and the northern Himalayan foothill tracts of India. Among the important collections are more accessions of *Atylosia rugosa, A. albicans, Dunbaria ferruginea, Rhynchosia albiflora, R. rufescens, R. suaveolens, R. rothii,* and *R. aurea.* Germplasm of *Dunbaria conspersa* from Jalpaiguri district in West Bengal was collected for the first time. We obtained *Atylosia acutifolia,* and *A.pluriflora,* which are new additions, and *A. reticulata* from Australia. Our gene bank now has 9936 accessions from 33 countries. Wild relatives consist of 164 accessions belonging to 39 species and 6 genera. The 352 recently added lines from Kenya, Tanzania, Thailand, etc., are at various stages of quarantine clearance.

During 1981/82, 1610 lines were rejuvenated, and 1472 lines were sown for rejuvenation in 1982/83. The recent collection of wild relatives from the Kumaon hills and the Western and Eastern Ghats of India also was rejuvenated.

We have completed characterizing most of the ICRISAT-developed lines, so their morphoagronomic descriptions are now available. In 1982/83 a total of 476 lines including new collections will be grown for characterization. In addition, to compare the suspected duplicates, we shall record morphoagronomic characters for 1674 lines; 2150 lines in all were sown for characterization in 1982/83.

Replicated evaluation to ascertain the performance of high-yielding, medium-maturing pigeonpeas continued; from the 60 lines originating from diverse genetic backgrounds evaluated in 1981/82 we selected 36 entries for a replicated yield potential trial in 1982/83. To identify more lines with photoperiodic insensitivity, we screened 1216 lines in 1982. So far 7256 lines have been screened at 1CRISAT Center, and 808 lines with potential for photoperiodic insensitivity were obtained. We sowed 400 of the 808 lines in late 1982 under an extended daylength to confirm photoperiodic insensitivity. The results will enable us to select more precisely the right genotypes needed for different geographical areas - and perhaps to extend pigeonpea cultivation into nonconventional areas and enable nonconventional planting times.

From the M2 and M3 generation of irradiated cultivar BDN-1, we identified several plants with translucent anthers containing sterile pollen. Test-crossed with the known heterozygous male sterile Ms-3A, two of them were confirmed true male steriles. Male sterility is now available in three maturity groups: ICP-10914 (early), BDN-1 (medium), and ICP-7188 (late) apart from other known male steriles.

In collaboration with ICRISAT pathologists, we now have 339 new germplasm accessions under various stages of rigorous screening for reactions to wilt, sterility mosaic disease, and blight. ICRISAT entomologists, who have screened 7785 germplasm lines since 1975 for reactions to pests, found some lines less susceptible to such major pests as *Heliothis armigera* and *Melanagromyza obtusa.* Of 150 lines screened in 1981/82, 39 more lines had some resistance to those pests. In cooperation with ICRISAT's entomologists, we established that the host range of the podfly, *Melanagromyza obtusa,* extends to several species of *Atylosia(A. lineata.*

To widen our germplasm in the pigeonpea breeding program, we crossed this Australian species, Atylosia latisepalus, *with cultivar NP(WR)-15, developed by the Indian Agricultural Research Institute, New Delhi.*

A. volubilis, etc.), *Rhynchosia,* and *Flemingia.* This knowledge helps scientists estimate the potential role of wild legumes in harboring pests from one crop season to the next. As a result of screening 45 accessions of wild relatives, such as *Atylosia scarabaeoides, A. sericea, A. lineata, Rhynchosia bracteata* and others, we identified 12 accessions with low susceptibility and other desirable traits.

The Biochemistry Unit has analyzed 1511 lines for important sulphur-containing amino acids such as methionine, cystine, and tryptophan, and 86 accessions of wild relatives for protein content and amino acid profile.

We continued our efforts to involve more exotic germplasm in the introgression work and successfully crossed one more Australian species, *Atylosia latisepala* with the pigeonpea cultivar NP(WR)-15. Attempts to cross *A. mollis, A. volubilis,* and *A. platycarpa* again failed, but further attempts will be made.

Documentation of 1980/81 evaluation data has been completed and the data are entered in the computer. The 1981/82 data are ready for the computer. The *Cajanus/Atylosia taxonomic* revision, begun in 1975, reached the final manuscript stage.

Chickpea Germplasm

Chickpea germplasm at ICRISAT now totals 12502 entries from 39 countries, not including about 400 recently acquired samples awaiting clearance by the Indian plant quarantine authorities. During the year, 45 accessions were added through fresh collections, 9 through correspondence, and 73 were newly developed or selected at ICRISAT. Our first chickpea germplasm collection mission to Ethiopia during January-February was successful, resulting in 210 samples, most of which are heterogenous populations composed of several morphologically distinct types. A second trip to the Jammu region of north India yielded 41 samples.

Morphoagronomic evaluation continued at both Patancheru and Hissar. At Hissar, a severe epidemic of foliar diseases devastated the crop so only 20 of 1400 entries sown could be harvested. Repeated tests of germplasm materials confirmed that some accessions such as P 324 and P 326, both originating from Bihar, India, are among the top grain yielders, and they are being used by breeders.

ICRISAT scientists have initially screened almost all the available germplasm and have confirmed resistance to fusarium wilt in 58 accessions, to dry root rot in 48 accessions, and to aschochyta blight in 154 accessions. Entomologists have confirmed good resistance against pod borer in 22 accessions. Of 58 wilt resistant lines, 18 also resisted black root rot. Eleven accessions were confirmed as resistant to chickpea stunt virus. Seed of all of the resistant stocks is available to research workers on request.

At one time all the eight wild annual *Cicer* species were assembled at ICRISAT, but *Cicer echinospermum* could not be maintained owing to its growing requirements. In some other species not enough seed could be multiplied under Patancheru conditions, but some *Cicer yamashitae* seed was salvaged. In future seasons these species are to be grown in extended daylight to induce early flowering, and produce more seeds.

Seeds of wild *Cicer* species are in heavy demand, primarily by research workers in basic and applied genetics. Some of the species have highly useful genes, but so far only *Cicer reticulatum* has been introgressed successfully with the cultivated chickpea. Perennial *Cicer* species are difficult to maintain under Patancheru environmental conditions.

Evaluation data on about 11 500 germplasm accessions grown at Hissar and Patancheru have been entered in the computer under the IDMRS system. It is now possible to sort out accessions in any combination required.

Groundnut Germplasm

Our collection of groundnut germplasm totals 10 211 accessions, an increase of 457 over last year. New accessions came mainly from Mozambique, Zambia, Ghana, Bolivia, Peru, and Brazil. In February 1982, a groundnut germplasm collection mission was undertaken to

This wild relative of groundnut, Arachis marginata, was collected in Brazil on a joint mission with EMBRAPA; the expedition obtained 38 wild accessions and 7 samples of cultivated groundnut. ICRISAT's accessions in groundnut germplasm now total more than 10000.

Brazil in collaboration with CENARGEN/EMBRAPA of Brazil and IBPGR. The trip, covering the valleys between the Araguaia and Tocantins rivers, yielded 38 wild *Arachis* accessions belonging to three sections namely, *Extranervosae, Triseminale,* and *Arachis,* and seven samples of cultivated groundnut. Collection trips in connection with other crops also yielded new groundnut accessions from Zimbabwe (32 samples), Burundi (1), Rwanda (1), and the Eastern Ghats, India (8).

Groundnut germplasm (about 1800 samples) from the Southern Regional Plant Introduction Station, Georgia, USA. is being transferred to ICRISAT, but most of it is still in quarantine. We also received 68 wild species accessions from Texas A & M University, some of which are under quarantine.

During the postrainy season of 1981/82, we multiplied and harvested about 3200 accessions, and we sowed about 3300 accessions in the 1982 postrainy season for rejuvenation.

During the rainy season of 1982, we evaluated 1587 accessions according to the IBPGR/ICRISAT descriptors. Screening of germplasm for various characters in collaboration with other programs has continued. Some lines with possible resistance to leafminer and *Spodoptera* have been identified, and are being tested further by the entomologists. Similarly, physiologists have identified some drought tolerant lines from the germplasm. Virologists confirmed that peanut mottle and peanut clump viruses in a few germplasm lines are not transmitted by seeds.

A booklet. Groundnut Descriptors, was jointly published by IBPGR and ICRISAT.

Minor Millets Germplasm

The 256 new accessions assembled from 8 countries during the year, raised the total to 4295. We recently acquired 250 accessions more—from Mexico (148), Italy (44), Tanzania (19), Zimbabwe (15), Kenya (10), Ethiopia (6), Mozambique (4), Burundi (3), and Rwanda (1)—which await release by the Indian plant quarantine authorities.

The collection expedition organized in collaboration with Prof. J.M.J. de Wet, University of Illinois, USA, in the Eastern Ghats of India added 148 samples, including new races of *Panicum sumatrense* and *Setaria italica,* from the tribal areas of Andhra Pradesh and Orissa in India.

In 1982, 1421 accessions of *Eleusine,* 1195 of *Setaria,* 735 of *Panicwn miliaceum,* and 243 of *Panicum sumatrense* were characterized and classified up to the subrace level in collaboration with the University of Illinois, USA.

Requests for germplasm samples of minor millets are increasing; we distributed 2981 seed samples to scientists in India and abroad during 1982, for a total of 19 323 samples since ICRISAT took charge of minor millets germplasm.

Germplasm Distribution

Every year thousands of germplasm samples of our mandate crops and six minor millets are distributed free to all who request and wish to use them in their local environments for crop improvement. Table 2 shows the numbers of germplasm samples distributed in 1982. All ICRISAT seeds are thoroughly inspected and cleared by the Government of India quarantine authorities before they are sent out, so ICRISAT distributes only clean, viable, safe seed.

All those who wish to exchange germplasm material with ICRISAT may simply write to the Genetic Resources Unit and request the type of sample they require, using the descriptor states as published by IBPGR/ICRISAT. Anyone wishing to send seed samples to ICRISAT should send the samples and the Phytosanitary Certificate by air to:

The Project Director
Central Plant Protection Training Institute
Ministry of Agriculture, Government of India
Rajendranagar, Hyderabad 500 030
Andhra Pradesh
INDIA

Prospective seed senders may contact us in advance for the green-and-white labels to be attached to each seed container. A copy each of the list of samples sent, the phytosanitary certificate, and the accompanying letter, if any, along with information about place and date of collection, altitude and latitude (if known), name of collector, and other pertinent information may be sent directly to our Genetic Resources Unit.

Looking Ahead

Further general and pointed collections are required from areas where genetic diversity still exists. New missions will be launched depending on funds, clearance from countries concerned, and existing collaboration. The new cold storage equipment will be installed in the recently completed building, for which the Japanese Government provided funds.

Multilocation testing of our germplasm at appropriate places will prove useful for our scientific clientele. Rejuvenation and evaluation in the areas of origin may aid in overcoming losses due to poor adaptation or quarantine restrictions.

Efforts to make the computer storage and retrieval system fully operational should facilitate selection and analysis. Major publications on taxonomic classification of pigeonpea and its wild relatives, and collaborative papers on classification of sorghum and minor millets are being processed.

The exciting results of the sorghum introgression project warrant continuation to ensure new variability for selection, adaptation, and use. Likewise, we shall continue introgression in other mandate crops in attempts to incorporate useful genes from wild relatives.

Viability studies of seed in long-term and medium-term storage will soon be started. We will do more specialized studies on the cytology of our crops and their wild relatives.

Already established links with the IBPGR and other national and international organizations will be further strengthened. A more collaborative working relationship and joint sorghum and millets germplasm activities will be promoted with INTSORMIL, in line with initial discussions in 1982.

Cooperative and joint genetic resource works will be further enhanced with NBPGR, ICAR, All India Coordinated Projects, and agricultural universities in India.

The idea of establishing a West African regional genetic resource activity will be pursued at the ICRISAT Sahelian Center in Niger. A similar regional center for eastern and southern Africa is also a major aim.

Publications

Journal Articles

APPARAO, S., MENGESHA, M.H., and SUBRAMANIAN, V. 1982. Collection and preliminary evaluation of sweet stalk pearl millet *(Pennisetum).* Economic Botany 36-3: 286-290.

HAMMONS, R.O., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N., and GIBBONS, R.W. 1982. Registration of peanut germplasm *Tifrust-1* to *Tifrust-4.* Crop Science 22: 453.

HAMMONS, R.O., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N., and GIBBONS, R.W. 1982. Registration of eight germplasm lines resistant to rust. Crop Science 22: 452-453.

HAMMONS, R.O., BRANCH, W.D., BROMFIELD, K.R., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N., GIBBONS, R.W., and GOLDIN, E. 1982. Registration of *Tifrust-13* peanut germplasm. Crop Science 22: 697.

HAMMONS, R.O., BRANCH, W.D., BROMFIELD,K.R., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N. and GIBBONS, R.W. 1982. Registration of *Tifrust-14.* Peanut germplasm. Crop Science 22: 692-693.

MURTY, D.S., PAT1L, H.D., PRASADA RAO, K.E., and HOUSE, L.R. 1982. A note on screening the Indian Sorghum collection for popping quality. Journal of Food Science and Technology 19: 79-80.

NAMBIAR, P.T.C., DART, P.J., SRINIVASA RAO, B., and RAMANATHA RAO, V. 1982. Modulation in the hypocotyl region of groundnut *{Arachis hypogaea).* Experimental Agriculture 18: 203-207.

RAO, N.K., VAN DER MAESEN, L.J.G., and REMANANDAN, P. 1982. Seed viability of pigeonpea stored in two environments. Netherlands Journal of Agricultural Science 30: 99-103.

Conference Papers

MENGESHA, M.H., and PRASADA RAO, K.E. 1982. Current situation and future of sorghum germplasm. Pages 323-333 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, ICRISAT, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

PRASADA RAO. K.E., and MURTY, D.S. 1982. Sorghum for special uses. Pages 129-134 *in* Proceedings of the International Symposium on Sorghum Grain Quality. ICRISAT, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

Miscellaneous

IBPGR/ICRISAT, 1980. Sorghum Descriptors. IBPGR, Rome, 28 pp.

IBPGR/ICRISAT, 1981. Groundnut Descriptors. IBPGR, Rome, 23 pp.

IBPGR/ICRISAT, 1981. Descriptors for Pigeonpea. IBPGR, Rome, 15 pp.

IBPGR/ICRISAT, 1981. Descriptors for Pearl Millet. IBPGR, Rome, 34 pp.

PRASADA RAO, K.E. 1981. Sorghum germplasm from Botswana. Sorghum Newsletter (North America) 24: 89-90.

PRASADA RAO, K.E., and MENGESHA, M.H. 1981. Genetic resources of sorghum from eastern Sudan. Sorghum Newsletter (North America) 24:101.

PUNDIR, R.P.S., RAO, N.K., and VAN DER MAESEN, L.J.G. 1981. Induced autotetraploidy in chickpea. International Chickpea Newsletter 4: 7-8.

PUNDIR, R.P.S., and VAN DER MAESEN, L.J.G. 1981. A spontaneous polycarpellary mutant in chickpea *(Cicer arietinum* L.). International Chickpea Newsletter 5: 2-3.


SORGHUM

Contents

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SORGHUM

The period reported here includes the 1981/82 postrainy season and the rainy season of 1982.

Our priority in the first half of the 80s is to develop and stabilize sorghum screening techniques for resistance and food quality traits. We advanced our ability to screen for important yield-limiting traits during the year. We now increasingly screen at different locations in India where limiting traits are best expressed.

We used cages to eliminate oviposition preference of shoot fly in evaluating shoot fly resistance, and learned more about the feeding behavior of the shoot fly maggot in relation to resistance.

The modified diet to rear stem borers produced more adults and larvae for field infestation.

We also developed techniques to increase the incidence of midge when needed in field work.

We can now effectively screen for resistance to grain molds, downy mildew, and anthracnose. Cooperative research by physiologists and pathologists improved our understanding of management factors relevant to screening for resistance to charcoal rot.

We have improved our techniques to measure emergence through a crust and a hot-soil surface as well as seedling drought resistance and recovery from stress, so we can now do large-scale testing of breeding stocks and germplasm. We have learned much about the rate leaves expand, which provides a potential technique to measure stress resistance, and can better evaluate aspects of nitrogen fixation in sorghum.

Using a new technique, we succeeded, for the first time, in effectively field screening against *Striga asiatica* in India.

A new venture is to gain better understanding of the chemical composition of colored-grain sorghums, and of grain-mold resistance—and possible crosses to improve resistance in white-Seeded sorghums.

Sources of resistance to downy mildew, *Striga,* shoot fly, and midge are now available in agronomically good varieties.

Advance in screening capability has improved our search for varieties with multiple resistance, and we began simultaneously incorporating several traits in improved varieties and hybrids.

Our improved varieties and hybrids have moved through testing systems in several countries and been released during the year. Sorghum varieties were released in Zambia, China, and El Salvador. India and Venezuela have varieties in advanced stages of testing.

Insect Pests

Shoot Fly (*Atherigona soccata*)

Biology. Population monitoring of shoot fly with fish-meal baited traps was continued at ICRISAT Center for the sixth consecutive year. The shoot fly population was low from mid-April through June and peaked the first half of August.

We replaced the square metal-pan trap that required frequent change offish meal and water with a plastic trap that requires no water. It is a plastic jar with fly entry holes all around (Fig. 1), containing a fish-meal dispenser and insecticide vial at the top and at the bottom a funnel whose outlet is attached to a collection jar. Fermented fish meal placed in the dispenser remains active 7 days. Tests to compare efficiencies of plastic and metal-pan traps showed no significant difference in total catches. The plastic trap, with slight modification and turning upside down, can also be converted to a live fly-catching trap.

Resistance screening. Sorghum's glossy trait is associated with shoot fly resistance, so all sorghum germplasm glossy lines were screened

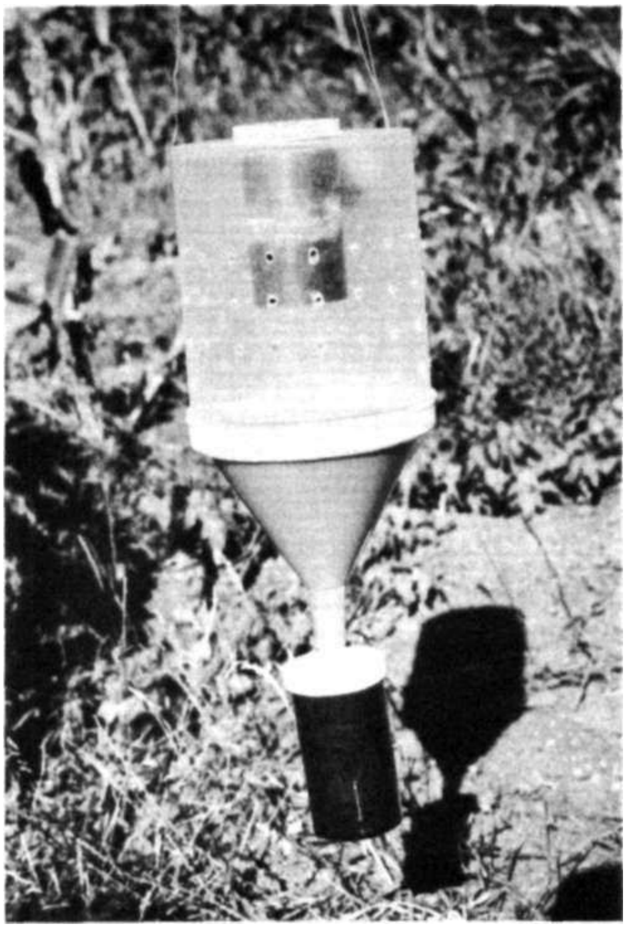

Figure 1. The new plastic shoot fly trap used at ICRISAT Center requires no water, unlike those used previously. Fermented fish meal, placed as bait in dispenser at top, remains active 7 days.

for shoot fly reaction in a replicated trial during the rainy and postrainy seasons. Shoot fly incidence was higher in the rainy season (mean 83.0%) than in the postrainy season (40.2%). Of 495 lines, 27 had less than 70% deadhearts in the rainy season; 36 had less than 20% deadhearts in the postrainy season. Some glossy lines are less susceptible to shoot fly, but glossiness alone does not make a line less susceptible.

We tested 80 previously selected lines in a replicated trial during the rainy and postrainy seasons to confirm their resistance to shoot fly. Under extremely high shoot fly pressure in the rainy season (mean 71%), 19 lines had less than 66%; incidence; under moderate pressure in the postrainy season (mean 47%), 40 lines had less than 41% incidence. Twelve lines were less susceptible in both seasons.

Three wild sorghum lines (two *Parasorghum* and one *Sorghastrum)* evaluated for reactions to shoot fly during the rainy season were not infested by shoot fly while nearly all of CSH-1 were attacked (92.5%).

Cage screening. From earlier works by Soto, we developed a cage technique to screen advanced shoot fly lines under uniform fly pressure and under no-choice conditions. To use the method, sow 44 sorghum lines in a 3.4 x 2 m seedbed with 15 cm between rows and 5 cm between plants in rows; 10 days after seed germinates, cover the bed with a 3.4 x 2 x 1 m screened cage. Release 75 pairs of flies collected from sorghum deadhearts (previously kept in sorghum seedlings for 4 days of preoviposition) or 100 flies collected from fish-meal baited traps. Remove the cage after 3 days and count eggs laid on the seedlings and after 7 days observe deadhearts formed. Then test the good lines identified in no-choice conditions to avoid ovipositional preferential behavior of the fly. For no-choice testing, cage 100 plants of each line in 1 x 1 x 1 m cage and release 20 flies per cage for 3 days and evaluate the material as explained before.

Our results from those two testing methods showed resistance under choice conditions higher than under the no-choice situation, particularly in lines IS 1082. IS 2122, and IS 2195 (Table 1). Ovary development of shoot flies during the preoviposition period is influenced by the presence or absence of host plants. Females exposed to sorghum seedlings during the preoviposition period began laying egg masses the 5th day; females not exposed did not reach full egg-laying capacity even after 9 days.

Multilocational testing. During 1982, we entered 15 advanced shoot fly tolerant breeding lines in the International Sorghum Shoot Fly Nursery (ISSFN)and the shoot fly nursery of the All India Coordinated Sorghum Improvement Project (AICS1P). Entries PS 14093, PS 14413, and PS 14533 were in advanced testing in the AICSIP shoot fly nursery for the second time.

Table 1. Incidence of shoot fly on indicated sorghum lines under choice and no-choice conditions, ICRISAT Center, 1982.

Sorghum lines	Choice condition		No-choice condition	
	Egg laying (%)	Deadhearts (%)	Egg laying (%)	Deadhearts (%)
IS 1082	53.1 (47.4) [a]	29.2 (30.5)	85.3 (67.2)	72.7 (58.9)
IS 2122	55.4 (48.3)	40.7 (39.5)	91.3 (73.9)	82.1 (65.2)
IS 2195	63.3 (53.9)	50.5 (45.4)	76.3 (61.8)	73.9 (60.1)
IS 4663	67.0 (55.9)	49.0 (44.5)	59.3 (50.8)	54.5 (47.6)
IS 4664	41.7 (40.2)	36.4 (37.1)	55.3 (48.1)	36.3 (36.9)
IS 5470	64.4 (53.7)	50.0 (44.8)	71.7 (58.7)	52.2 (46.4)
IS 5484	48.1 (43.9)	41.8 (40.0)	72.1 (58.7)	58.7 (50.4)
IS 5566	47.7 (43.8)	40.5 (39.2)	62.8 (52.6)	55.3 (48.1)
IS 18551	57.2 (49.9)	42.7 (40.6)	51.6 (46.0)	44.0 (41.5)
PS 21171	70.1 (57.5)	46.7 (43.1)	58.6 (50.2)	51.3 (45.8)
PS 21217	48.3 (44.0)	32.7 (33.9)	54.9 (47.9)	40.4 (39.5)
PS 21318	51.1 (45.7)	43.8 (41.3)	60.8 (51.3)	48.3 (44.1)
CSH-1	93.1 (75.0)	92.3 (75.1)	100.0 (85.9)	95.3 (78.5)

a. Figures in parentheses are arc sine transformations.

Entries PS 21171, PS 21217, and PS 21318, were less susceptible across locations in Upper Volta, Thailand, and ICRISAT Center, and under a no-choice situation at ICRISAT Center; PS 21318 was the most promising entry in the ISSFN at Samara, Nigeria.

Breeding for resistance. Using PS 18817-3. PS 18822-4, PS 18601-3, PS 19230, and PS 14413 as shoot fly resistant parents, we generated 208 F_2 populations, tested them in late September 1982, and made 325 agronomically elite selections with shoot fly resistance comparable to that of the original sources.

From 1446 advanced breeding progenies (F_5, F_6, and F_7) tested under heavy shoot fly pressure (90% deadhearts in the moderately resistant check), we selected 76 progenies. Six were non-restoring when crossed to a cytoplasmic male-sterile line.

Source diversification. Our studies on source diversification indicate that good genetic diversity for shoot fly resistance exists and that different sources have different blocks of resistant genes. So pooling diverse gene blocks may increase resistance.

Multiple resistance. In 1982 rainy season tests, PS 18601-3 showed good resistance to downy mildew, leaf rust, and shoot fly; PS 14413, to shoot fly, stem borer *(Chilo),* and shoot bugs; and PS 18817-3, to shoot fly, shoot bug, and leaf rust.

Entries PS 14103, PS 10597, and PS 10607 yielded 2500 to 4000 kg/ha with good management.

Stem Borer (*Chilo partellus*)

Resistance screening. During the rainy season we tested 374 previously selected germplasm lines in a replicated trial at Hissar, India, under natural borer infestation. Compared with a mean incidence of 72.2% deadhearts in the test material, 56 lines showed less than 40% incidence. The least susceptible lines originated from: India 57.5%, Nigeria 14.8%, USA 13.0, Sudan 7.4%, Uganda 3.7%, and Zimbabwe and Ethiopia 1.9% each. Most of the lines (74.5%) belong to durra sorghum, whereas 18.2% are durra bicolor. Of the 1254 lines selected last year at Pantnagar, India, under low insect pressure, 106 were retested at Hissar this year; these will be tested further.

Of 62 advanced, less-susceptible, shoot fly breeding lines (primarily in F_6 and F_7 material) tested in three replications, 3 lines (PS-14413, PS-13827, and PB-8104-1) were exceptionally promising for resistance to *Chilo.* Of these, PS-14413 also had good resistance to shoot fly. All three lines have reasonably good agronomic backgrounds.

Mass rearing on artificial diet and field infestation. By developing a new egg-laying cage and a better moth-collection device, we improved rearing *Chilo partellus* on artificial diets. In the new cage, females lay eggs through holes in a screen that forms a square grid pattern on the butter paper. The moth-collection device consists of a suction cleaner and exchangeable collection jars that allow female and male moths to be collected separately and transferred easily into egg-laying cages. The kidney-bean diet previously used was replaced by a chickpea-based diet that increased female output 60%. First instar larvae are distributed in the field with the bazooka, developed at CIMMYT, which drops larvae and carries them into plant whorls.

During the postrainy season, 2 ha of sorghum source material and breeding lines were infested when the crop was 26 to 30 days old with artificially reared 1st instar larvae (5 to 7/plant).

Multilocational testing. Results received so far from the 1982 International Sorghum Stem Borer Nursery (ISSBN) have been encouraging. PB-8294, PB-8258, and PB-8281, identified as tolerant to *Chilo* in India, performed well against *Busseola* at Samaru, Nigeria—the best among all ISSBN test entries, rated 2.0,2.4, and 2.5 (l to 9 infestation index) against 6.2 for the local susceptible control.

Breeding for resistance. To initiate our stem borer resistance breeding program, we made 50 hand crosses by using PS-14413, PS 13827, and PB 8104-1 as resistant source parents. Now we will concentrate on creating stable, high-yielding, borer-resistant material.

Sorghum Midge (*Contarinia sorghicola*)

Biology. Sorghum midge development from egg to adult was studied on three resistant (AF-28, IS-12666C, and TAM-2566) and two susceptible (CSH-1 and Swarna) cultivars. At 50% anthesis, 60 midge flies per sorghum head were confined on each of three heads of each genotype to lay eggs. Numbers of flies that emerged from infested florets were counted daily. Development periods and numbers of flies emerging from resistant and susceptible cultivars varied widely (Table 2). Emergence in susceptible cul-

Table 2. Post-embryonic development of sorghum midge in indicated genotypes, ICRISAT Center, rainy season 1982.

Sorghum	Days after inoculation												Total
genotype	15	16	17	18	19	20	21	22	23	24	25	26	flies
	Midge emerged/head[1]												
AF-28	-	-	-	-	-	-	9	9	4	2	-	-	24
IS-12666C	-	-	16	16	12	15	9	7	5	3	1	3	86
TAM-2566	-	-	-	-	-	19	8	8	4	5	2	4	50
CSH-1	21	38	49	63	41	34	33	20	9	6	-	-	314
Swarna	-	-	59	30	43	50	52	47	22	9	4	-	316

1. Based on caged earheads inoculated with 60 midge flies/cage.

tivars (Swarna, CSH-1) started much earlier than in resistant cultivars except IS-12666C, which indicates that less susceptible cultivars can reduce population buildup, and may over time reduce the number of generations by prolonging their development period.

Midge populations were monitored on sorghum earheads at half anthesis stage at ICRISAT Center. Sorghum plantings were made fortnightly, and midge flies on sorghum heads at half anthesis were counted daily. Midge activity peaked in October with a second peak in February-March. With the onset of monsoon rains, the diapausing midge population emerged in July from infested sorghum earheads carried over from the previous season. Low midge populations were active year round.

Resistance screening. The variation of sorghum germplasm/breeding material in time to flowering and the fluctuating midge population constitute a key problem in screening for midge resistance. To increase the midge population, we used two methods: mixed maturity spreader rows planted 20 days earlier and midge infested heads. The methods were used alone and in combination as indicated in Figure 2. Midge damage was recorded in 2000 florets picked at random from 25 heads at the center of each plot (Fig.2). Midge damage was highest in the plot with spreader rows with infested earheads scattered on the ground between test entry rows, which increases midge population 3 to 5 times. But prevailing temperature and humidity largely determine the population buildup.

To screen cultivars under uniform insect pressure, we developed a head cage (25 cm long and 16 cm in diameter). The results indicated that 40 midge flies collected in the morning (9-11 am) and introduced into the cage on two consequent days at the half anthesis stage (Fig. 3) produced maximum damage on susceptible cultivar CSH-1. Midge in cages covered by blue bags did more damage than those in red and yellow bags. A set of 21 lines (replicated 3 times with 5 heads inoculated per replication, containing resistant and susceptible cultivars) were screened in the head cage (Table 3). The results indicated that DJ-6514, TAM-2566, and IS-12666C were the most

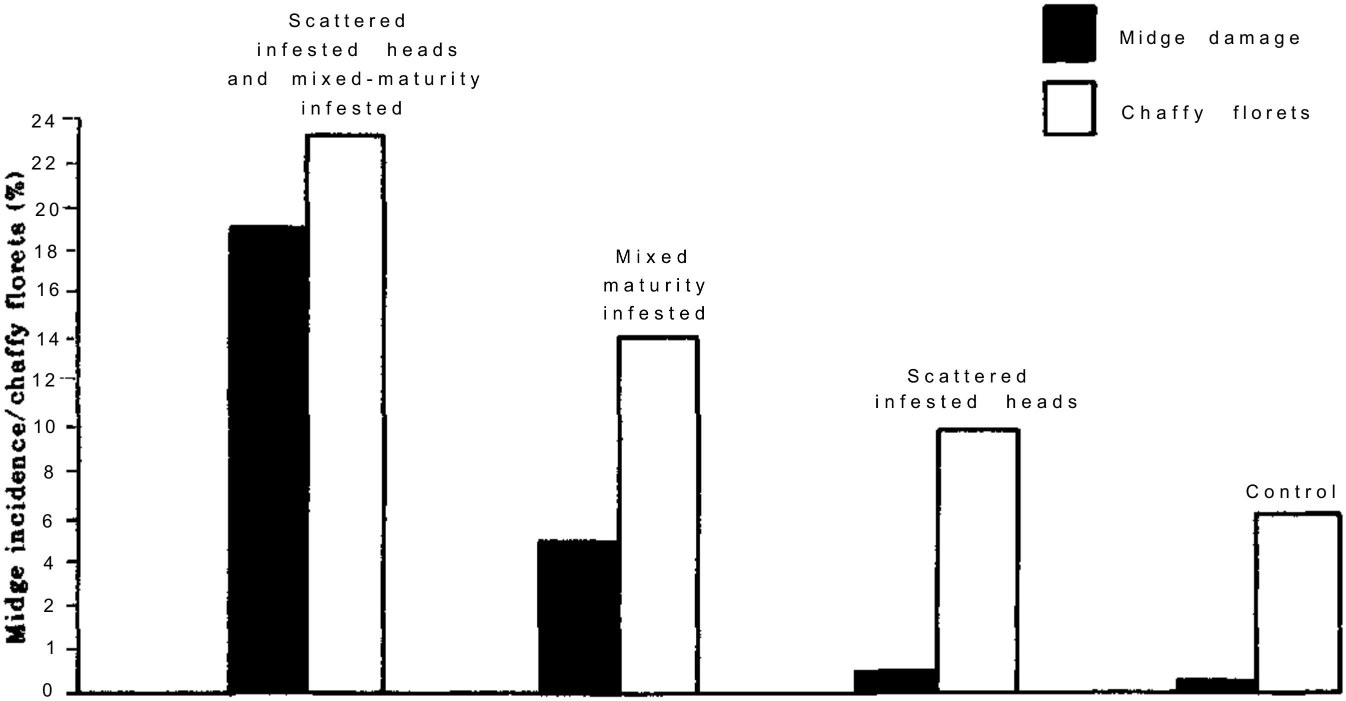

Figure 2. Effect of mixed-maturity spreader rows and inoculation with midge-infested heads on sorghum hybrid CSH-1 (based on observation of 2000 florets from 25 heads), ICRISAT Center, postrainy season 1981/82.

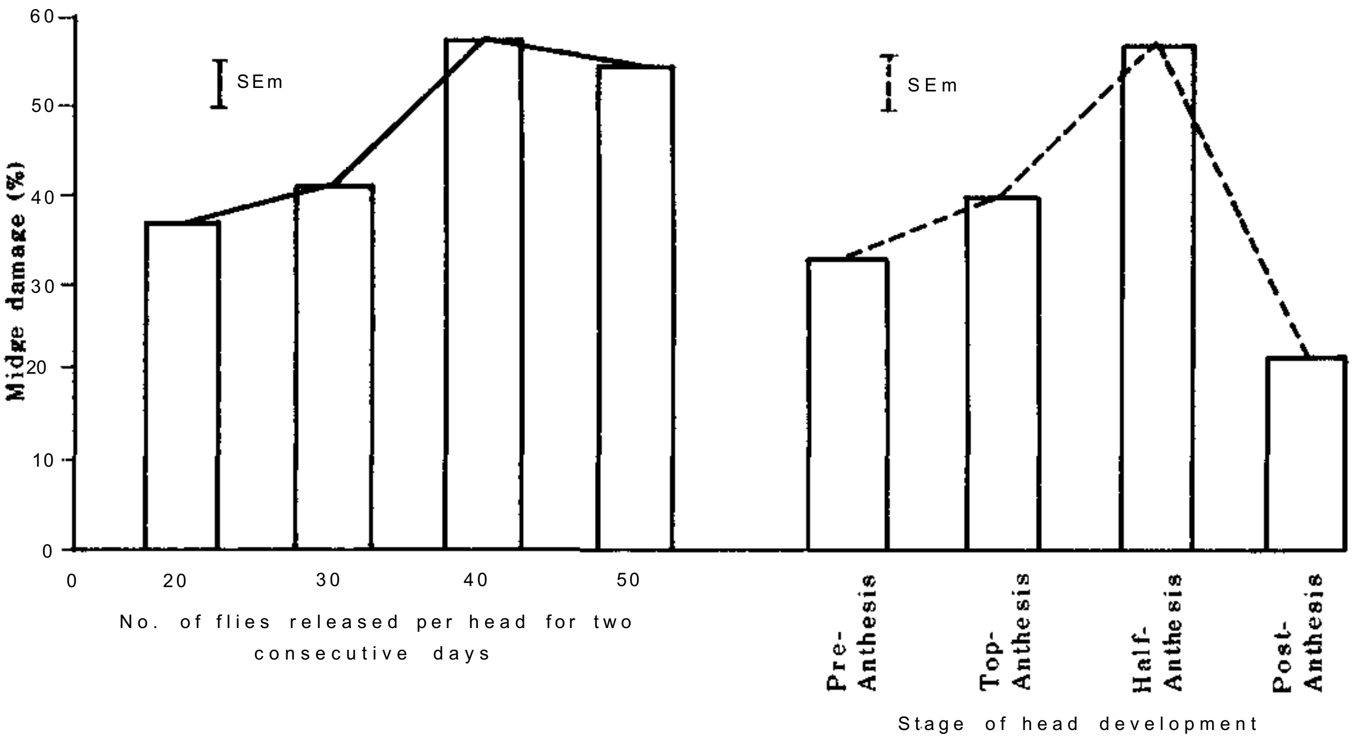

Figure 3. Midge damage in sorghum heads (CSH-1) at different levels of midge pressure and stages of head development in head cage conditions, ICRISAT Center, 1981/82.

resistant lines. Several lines considered resistant under natural infestation were quite susceptible under the head cage.

Using the head cage, we screened 300 germplasm and breeding lines, selected 60 promising lines, and entered the best 10 of them in the International Sorghum Midge Nursery(ISMN), which is available to interested scientists in India, Africa, and Latin America.

Of 4500 germplasm lines screened for midge resistance at Bhavanisagar and Dharwar in India under natural infestation, 80 were retained for further testing.

Breeding nurseries. In nursery tests to identify midge-resistant breeding lines, sorghum line PM-7348 has been found less susceptible at locations in India, Argentina, and El Salvador, as also under caged conditions. The line is now used extensively in ICRISAT's work as an improved midge-resistant source for new crosses.

Breeding for resistance. Of 26 F_2 populations tested under moderate midge pressure at Dharwar, we selected 216 less infested derivatives. The F_2 populations were derived from crosses involving TAM-2566 and DJ-6514. which are resistant to midge.

At Dharwar, we also tested 1645 advanced midge-resistant, breeding progenies (mostly F_5, F_6, and F_7 generation) under high midge pressure, and selected 145 promising progenies to be advanced.

Six varieties yielded 60 to 70% as much as CSH-5 (hybrid check) at ICR1SAT Center under no midge infestation and had good resistance to leaf rust. All midge-resistant lines from these tests are being crossed with an A-line to see if they are nonrestoring. After confirming their restoration reaction, we will convert the best midge-resistant, nonrestorer lines into male-sterile seed parents to produce midge-resistant hybrids.

Head Bug (*Calcoris angustatus*)

In continuing studies on the biology of *C. angustatus,* we observed that females lay an average

Table 3. Midge damage on caged earheads of indicated sorghum cultivars, ICRISAT Center, rainy season 1982.

Cultivar	Florets with midge larvae (%)	Chaffy florets (%)
DJ-6514	2.33	19.00
TAM-2566	18.67	27.00
IS-12666C	24.33	35.00
IS-12573C	36.33	63.33
IS-12612C	39.33	60.33
EC-92792	42.67	59.67
S-GIRL MR-1	45.33	64.33
IS-2327	46.00	59.00
EC-92794	51.67	75.00
IS-2579C	53.67	64.67
1S-6I95	54.33	86.67
1S-12664C	55.00	63.00
EC-92793	56.67	66.00
ENTM-3	58.33	72.67
IS-12608C	58.33	70.33
IS-2328	58.33	67.67
IS-12611	61.00	71.67
IS-28I6C	66.00	79.00
IS-1151	66.33	79.33
CSH-1	70.33	84.67
IS-I510	71.00	80.33

182 ±21 eggs after a 2- to 4-day preoviposition period during the rainy season, and 113 ± 12 eggs during the postrainy season after a preoviposition period of 5 to 8 days. Eggs hatched averaged 93 ±2% during rainy and 73 ±11% during postrainy season. The females in cages survived 14 to 23 days during the rainy season and 12 to 23 days during the postrainy season.

We monitored headbug populations at fortnightly intervals at ICRISAT Center, by sampling 10 sorghum heads selected at random in the postanthesis to milk stage. Maximum bug activity was observed during September-October and in late February to early March (postrainy season), with little or no bug activity during May-July.

Resistance screening. Perhaps because of extremely high insect pressure, none of our 1080 basic sorghum germplasm collection lines was considered less susceptible when screened for headbug resistance during the rainy season. The head-cage technique helped overcome the high insect pressure. Releasing 15 field-collected pairs of headbugs at preanthesis gave maximum headbug counts and grain damage on CSH-1 (highly susceptible). Of the 180 lines tested with head cage, 25 were retained for further testing.

Armyworm (Mythimna separata)

Biology. No moths were caught in light traps during June over the last 3 years even though larvae were present 7 to 10 days after monsoon rains began during June. Maximum light-trap catches of moths were in September after maximum larval populations in August. Light traps apparently do not effectively detect the initiation and peak infestations. Maximum moths were caught during a period of low or no rainfall after 2 to 4 weeks of moderate to high rainfall, moderate temperatures, and high humidity. *Apanteles reficrus* was the most important parasite recorded on the larvae.

Resistance screening. A resistance-screening technique was standardized in the greenhouse. To use it, expose 15-day-old seedlings (10 seedlings/pot) to first (@ 5 larvae/plant) or third instar larvae (@ 1 larva/plant) with larvae confined to seedlings with plastic cages (11 cm diameter, 25 cm high) with four mesh wire ventilators (5 cm diameter) on the sides and one at top.

Of 500 glossy lines screened using third instar larvae, we selected 50 for further testing.

Research in collaboration with the Regional Research Laboratory, Hyderabad, on neem extracts showed that fraction 'G' of the alcoholic extract of dried fruits was the most active against *Mythimna separata* larvae. Further purification and fractionation led to our identifying three fractions with strong antifeedant and antimoulting properties.

Diseases

Grain Molds

Resistance to grain molds in colored-grain sorghums. After identifying high grain mold resistance in colored-grain sorghum germplasm accessions (ICRISAT 1981 Annual Report), we began testing for stability of resistance at grain mold hot-spot locations. Early results indicated that 15 genotypes maintained high resistance at five locations: in Farako Ba, Upper Volta, and in India at Bhavanisagar, Pantnagar, Navsari, and Patancheru.

Seventy-eight sorghum lines have been identified as highly resistant to grain molds. Table 4 gives the genetic diversity and origin of selected identified resistant sources.

Although we have not completely characterized seed anatomy, lines IS-14375, IS-14380,1S-14384, 1S-14390. and IS-21599 appear to have no testa.

Breeding for resistance. This year we investigated possible transfer of mold resistance in colored-grain sorghums to white-seeded, agronomically-elite cultivars. Preliminary results indicate that genes for colored grain, tannin content, and mold resistance are not well correlated, so it may be possible to transfer mold resistance genes to white-seed sorghums. We have made appropriate crosses involving a range of grain mold resistant, colored-grain sorghums and white-seeded types to understand the relationship between seed color, tannin content, and mold resistance. Progenies derived in the F_2 and F_3 generations will be screened during the 1983 rainy season to see if white-seeded segregates with high mold resistance can be identified.

Sorghum Downy Mildew (SDM)

Destructive potential. The destructive potential of SDM was seen in the 1981 rainy season at ICRISAT Center when an epidemic of the disease resulted in more than 20% of the plants with systemic disease in 19 of 98 ha of sorghum. Some fields sown between 23 June and 7 July had more than 70% of their plants with systemic disease. In Tamil Nadu state, southern India, a survey in

Table 4. Pedigree, race, plant color, and origin of selected colored grain sorghum lines that resist grain molds.

Sorghum lines	Pedigree	Race	Origin
IS-694	Sugar drip	Kafir-Bicolor	Mexico
IS-2867	Sugar drip	Bicolor	South Africa
IS-3547	Rapbol	Caudatum[1]	Sudan
IS-8545	Morasa 74	Caudatum	Ethiopia
IS-8614	E-67 Kawanda	Caudatum	Uganda
IS-8763	E-254	Kafir	South Africa
IS-8848	E-513	Caudatum-Bicolor	Kenya
IS-9353	No. 169	Caudatum-Kafir	South Africa
IS-9487	No. 364	Caudatum-Kafir	South Africa
IS-14384	Boane	Guinea	Zimbabwe
IS-15221	2-1-8-3 b	Durra-Caudatum	Cameroon
IS-17141	Bomkum	Durra-Caudatum	Nigeria
IS-20620	HW-746	Durra-Caudatum	USA
IS-21454	SAD-182	Guinea-Caudatum[1]	Malawi
IS-22296	PMK-110	Durra	Botswana

1. = tan; all others, pigmented.

December 1982 of the major sorghum-growing districts (Coimbatore, Madurai, Trichy, Salem, and Periyar) which account for 78% of the 720 000 ha total sorghum area in that state showed SDM widespread on both sorghum and maize. Up to 95% of the plants in a number of fields were diseased. That and its importance in the Americas and parts of Africa make downy mildew a priority problem.

Field resistance screening. We successfully used the infector-row technique based on wind borne conidia of the SDM pathogen (see 1CRISAT 1981 Annual Report) to screen more than 4000 sorghum lines for SDM resistance during the rainy season at Dharwar. The components and procedures of the technique follow:

1. Sow in infector rows a highly SDM-susceptible sorghum line (DMS-652 or IS-643) on which the pathogen produces abundant conidia.
2. Establish SDM disease in infector rows by incubating germinated (24 hr) seeds between SDM systemically infected leaf pieces at 20°C in a dark, humid chamber for 18 to 20 hr before sowing to ensure that all infector-row plants are infected.
3. Plant the test material after infector row seedlings have become established and show sporulation of SDM at about 20 to 25 days after sowing.
4. Plant five rows of test material between two rows of infector rows. Plant the middle row of the five rows to the same SDM-susceptible variety as the infector rows, to indicate SDM pressure and as a susceptible check for the four test rows.

An infector-row technique, based on windborne conidia of the pathogen causing downy mildew in sorghum, was used successfully to screen more than 4000 lines at Dharwar, Karnataka, India; 44 lines were found resistant and will be retested.

5. Evaluate the check and test material for SDM at seedling, flowering, and maturity stages, considering material with 5% infected plants as resistant.

Downy mildew development and conidial production in the infector rows were high; there was 100% systemic disease in check rows, indicating adequate disease pressure for evaluating test material.

Of 2804 germplasm and 1126 breeding lines screened, 151 and 334 lines, respectively, were resistant to SDM; 44 were free from the disease. Those 44 will be further evaluated in 1983.

Reaction of wild and weedy sorghum germplasm to SDM. In our search for genetically diverse sources of resistance to SDM, we began screening wild and weedy sorghum germplasm in the ICRISAT collection, using conidial inoculum in infector rows. The material screened was either highly susceptible to SDM (>50% plants with systemic disease) or free from it. Resistance was found in several accessions of *Sorghum versicolor* (IS-14346, IS-14350) and *S. bicolor* subspecies *arundinaeeum* (IS-14218, IS-14232, IS-14302, IS-10710, R.579 P1/1) and *drummon-rfn* (IS-14387, IS-21401).

Multinational testing. The 1981 International Sorghum Downy Mildew Nursery (ISDMN) included 12 locations in 7 countries, but disease pressure was sufficient at only 5 locations (Dharwar, Mysore, and Coimbatore in India and Pergamino and Manfredi in Argentina). At those locations, as in previous years, QL-3 and its sister lines 2-7 and 2-26 were free from downy mildew. Other lines with 5% downy mildew compared with 65 to 100% insusceptible cultivar DMS-652 were IS-8185, IS-8283, IS-3443, IS-8607, IS-7528, and IS-3547. It was the first year in the ISDMN for these six entries.

Breeding for resistance. Use of the large-scale field-screening technique at Dharwar made it possible to identify SDM resistance in breeding material, Of 11 F_6 bulks screened 2 (DM-96 and DM-103) were as free from SDM as their resistant parent, QL-3. And they had tan plants and better grain quality than QL-3's red grain.

We screened 199 F_6 progenies from crosses involving QL-3 for resistance and made 419 selections to be advanced and screened. In the 1982 rainy season, 220 new crosses were made with QL-3 and the QL-3 derivatives as the SDM resistant donors; the resulting F_2 segregating populations will be screened for resistance in the 1983 rainy season. Forty-nine F_2 populations derived from crosses involving new sources of resistance to SDM (IS-3443 and IS-8283) were screened for resistance, and 30 selections made for further screening in 1983.

Charcoal Rot

Effects of various factors on incidence. Using a split-split-plot design, we studied the combined effects of different levels of nitrogen, plant population, plant inoculation, and drought stress on charcoal rot incidence (measured as lodging—the first apparent symptom) in the highly susceptible sorghum hybrid CSH-6 planted in an Alfisol 15 October 1981. We used three nitrogen levels (N_1, N_2, N_3 = 20, 60, and 120 kg/ha, main plots), three levels of plant population (6,12, and 18 plants/m^2, subplots), and three inoculations (none, with pathogen-colonized toothpick, and with sterilized toothpick; sub-subplots).

The crop was uniformly irrigated to flowering, then a gradient of soil moisture was imposed. Eighteen rows, in subplots, were sown parallel to a line-source sprinkler irrigation system (LS), and divided into nine 2-row observation units. Water during grain filling from four LS irrigations 69, 83, 93, and 103 days after planting was 14.2 cm in the observational unit nearest to LS; it then decreased linearly and continuously so the last unit received less than 1 cm (Fig. 4). That the water application gave a linear decrease in crop transpiration was confirmed by measuring the leaf-air temperature differential (Fig. 4).

As the experiment was conducted during the milder postrainy season, crop growth and grain yields were little affected; yields decreased slightly after the fourth unit (up to about 6.5 m from the LS). The effect of stress on disease

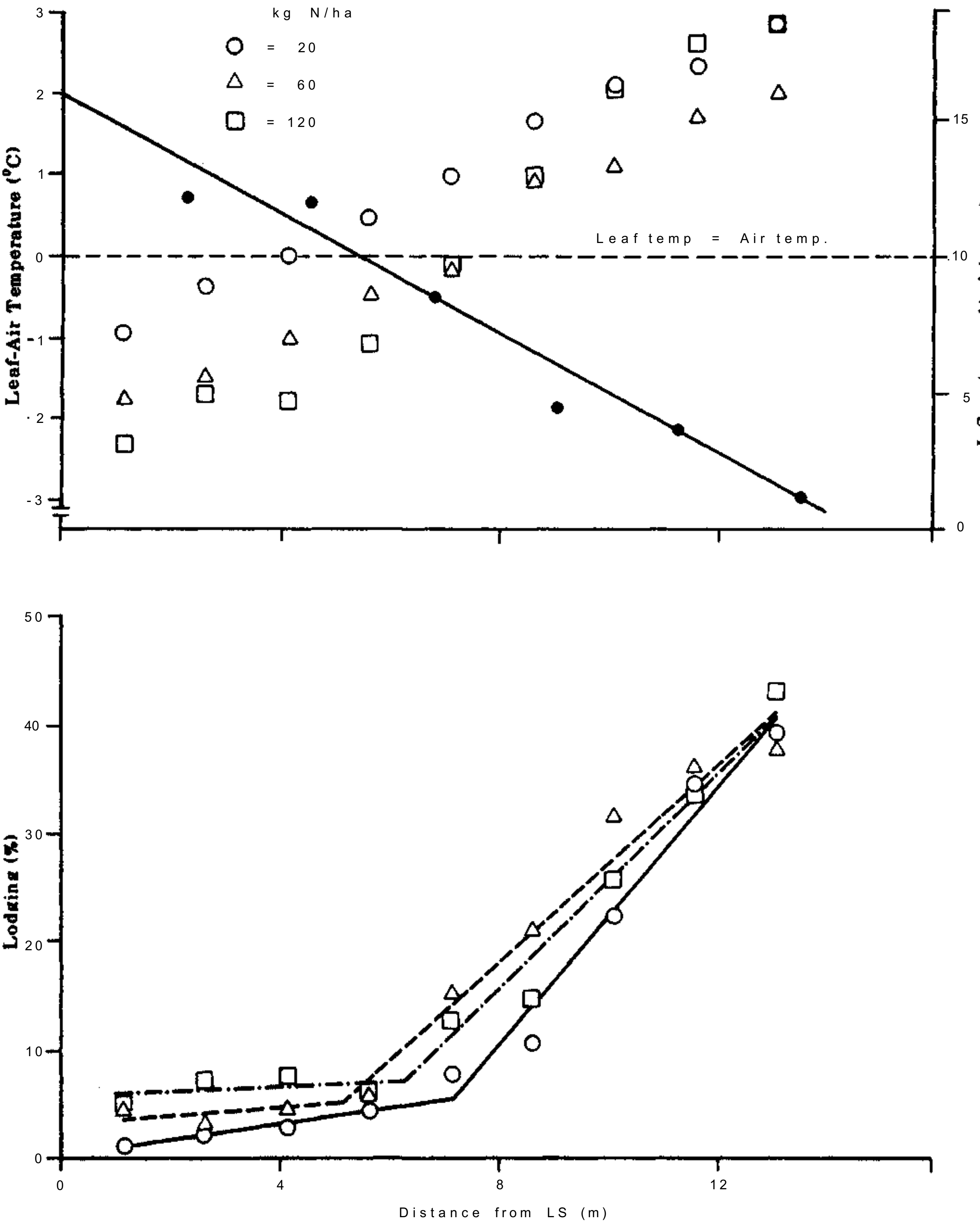

Figure 4. Relationships between distance from line-source sprinkler (LS) irrigation water applied and leaf-air temperatures (top) and, lodging percentage in each nitrogen treatment (bottom). Regression equations in Table 5A.

Table 5 A. Linear regressions between distance from line source sprinkler (X; corresponds to degree of soil moisture stress) and other variable (Y) [see Figure 4].

Equation	rse	r
A. Water applied through LS (cm)		
Y = 15.43-1.07X	1.04	0.98
B. With leaf-air temperature (°C)		
N_1: Y = 1.30-0.32X	0.10	0.99
N_2: Y = 2.34-0.34X	0.18	0.99
N_3: Y = 3.25-0.48X	0.41	0.98
C. With lodging (%)		
a) Upto 6.3 m from LS		
N_1: Y =0.14-0.71X	0.41	0.97
N_2: Y = 2.80-0.42X	1.12	0.67
N_3: Y = 5.80-0.22X	1.20	0.39
b) From 6.3 to 13.9 m		
N,: Y = -35.75+5.78X	2.99	0.98
N_2: Y = -17.23+4.44X	2.72	0.98
N,: Y = -23.24+4.88X	2.47	0.99

LS = Line source.
N_1, N_2, N_3, = Nitrogen levels.

incidence (lodging) was apparent in the whole range of water supply. Lodging increased under both high nitrogen and high plant population, and interactions among all three factors were significant (Table 5B).

Leaves in the four observational units closest to LS were cooler than the air, indicating high transpiration (Fig. 4), and lodging was low in these units (Fig. 4). Farther from LS leaves were hotter than air and lodging increased linearly with distance from LS, i.e., with increasing drought stress.

Charcoal rot developed equally well in all three inoculation treatments, indicating that it is not necessary to inoculate plants to cause charcoal rot.

We will use the LS information in designing a screening technique for expression of disease with suitable management practices incorporated to increase sorghum production with minimum lodging.

Fungi associated with root and stalk rot and lodging. The three experimental sets where we made fungal isolations from roots and stems of lodged plants were: (1) breeders' yield trials at Dharwar, (2) experiment on charcoal rot incidence in susceptible hybrid CSH-6 grown under depleting soil moisture, at Dharwar, Nandyal, Madhira, and ICRISAT Center, (3) experiment on charcoal rot incidence in CSH-6 under induced drought stress at Dharwar, ICRISAT Center, Nandyal, and Wad Medani in the Sudan. Results showed that *Macrophomina phaseolina* was the predominant fungus and that

Table 5 B. Lodging percentages in CSH-6 sorghum under three nitrogen levels and three plant populations, ICRISAT Center, 1981/82.

Plant population (no./ha)	Lodging (%)			
	N_1 (20 kg N/ha)	N_2 (60 kg N/ha)	N_3 (120 kg N/ha)	Mean
66675	7.6	3.8	6.4	5.9
133 350	13.9	18.4	17.0	
266 700	29.4	37.0	36.2	34.1
Mean	17.0	19.7	20.4	19.0

SE comparing 2 levels of nitrogen ± 1.48
SE comparing 2 levels of plant population ± 1.58
SE comparing 2 levels of plant populations at the same level of nitrogen ±2.74
SE comparing 2 levels of nitrogen at the same level of plant population ±4.97

Fusarium moniliforme was nearly always associated with it, particularly in the roots. The mode of root infection and interactions of the two fungi are being investigated.

Incidence under increasing drought stress. In India sorghum sown near the end of the rainy season is predisposed to charcoal rot by developing and maturing while soil moisture is depleted. We studied the incidence of charcoal rot in three cultivars (CSH-6, BJ-111, and E-36-1) at three plant populations (6, 12, and 18 plants/m^2) and different planting dates at four Indian locations (Dharwar, Madhira, Nandyal, and 1CRISAT Center). Planting dates were: Dharwar 15, 25 Sept, and 15,25 Oct; Madhira 4 Sept and 10 Oct; Nandyal 12, 24 Oct, and 4 Nov; ICRISAT Center 14, 23 Oct, and 7, 16 Nov. Hybrid CSH-6 lodged badly (50-100%) at all locations, and under all plant populations and planting dates. Lodging in germplasm line E-36-1 ranged from 0 to 9%. Visual examination of roots and stems and fungal isolations from plants that had not lodged in E-36-1 showed them, like lodged plants, infected by the charcoal rot pathogen *M. phaseolina.* So E-36-l's low incidence of lodging apparently is from charcoal-rot tolerance.

Table 6. Anthracnose-resistant sorghum breeding lines with high grain-yield potential (>4,000 kg/ha).

Pedigree	AICSIP[1] designation
(CSV-4 x G.G. 370)-2-1-1-3	-
(SC-108-3 x CS-3541)-14-1	SPV-476
(IS-12611 x SC-108-3-4-1-9	-
[(SC-108-3 x Swarna) x E-35-l]-6-2	-
[((IS-12622-C x 555) (IS-3612-C x 22198)-5-l)E-35-l]-5-2	SPV-475
[(148 x E-35-1)-4-1 x CS-3541 deriv.]-5-5-2-l	-
[IS-12611 x (SC-108-3 x CS-3541)-38-1]-3-1	-
(TAM-428 x E-35-1)-4	-

1. AICSIP = AH India Coordinated Sorghum Improvement Project.

Leaf Diseases

Anthracnose

As in previous years research on anthracnose (*Colletotrichum graminicola* [Cesati] Wilson) was conducted at Pantnagar, where disease incidence and severity on susceptible sorghum lines are high under natural infection during the rainy season.

Observations in 1982 showed that common weeds *(Eleusine indica* [L.] Gaertu, *Echinochloa colonum* [L.] Link, *Digitaria sanguinalis* [L.] Scop, and *Dactyloctenium aegypiium* [L.] Rioter) growing in and around plots, and sorghum-plant debris in the soil, were the main sources of anthracnose inoculum in field screening at Pantnagar. The pathogen sporulated abundantly on those weeds and on sorghum-plant debris but the susceptible cultivar M.P. Chari, used as an infector row, showed no sporulation although infection was heavy.

In the 1981 rainy season we screened 3171 germplasm and 609 advanced-generation breeding lines for resistance to anthracnose, and selected 575 lines for advanced screening in 1982, which confirmed high resistance to anthracnose in 96 breeding lines and 41 germplasm lines. The best breeding lines with high grain-yield potential from breeders' trials are given in Table 6.

Rust

Resistance screening. In preliminary screening of 762 advanced generation breeding materials and 333 germplasm lines at Dharwar with the infector-row technique (ICRISAT Annual Report 1981), we selected 262 lines as resistant to rust for further screening in 1983. In advanced screening of breeding material selected in 1981, 147 of 245 lines were selected as resistant to rust. Some of these breeding lines have high grain-yield potential (Table 7).

Resistance to anthracnose and rust. Material screened for resistance to anthracnose at Pantnagar is also screened against rust at Dharwar.

Table 7. Rust-resistant sorghum breeding lines with high grain-yield potential (>4,000 kg/ha).

Pedigree	AICSIP designation
E-35-1 x US/R-408-8-2	-
IS-2550 x Nigerian-8-1-2	-
Indian synthetic-323-1-4-1	-
(SC-108-3 x CS-3541)-51-1	SPV-352
(IN-15-2 x CS-3541)-15-2-3	SPV-355
(SC-108-4-8 x CS-3541)-40-1	SPV-353
(SC-108-3 x CS-3541)-3-1	SPV-350

This year we identified 25 germplasm and 46 breeding lines with resistance to both anthracnose and rust. Notable among the breeding lines were SPV-351 in minikit trials and SPV-386 in advanced yield trials in the All India Coordinated Sorghum Improvement Project (AICSIP).

Multilocational Testing for Resistance to Leaf Diseases

Thirty entries in the 1981 International Sorghum Leaf Disease Nursery (ISLDN) were evaluated for resistance to anthracnose, leaf blight, rust, grey leaf spot, sooty stripe, zonate leaf spot, rough leaf spot, oval leaf spot, and tar spot under natural infection at Indoreand Udaipur (India), Ocotlan (Mexico), Samaru (Nigeria), Islamabad (Pakistan), Laguna (Philippines), Farm Suwan (Thailand), Farako Ba (Upper Volta), and Chilanga (Zambia).

As in previous ISLDN nurseries, the best entry was E-35-1. It resisted anthracnose, leaf blight, rust, zonate leaf spot, sooty stripe, oval leaf spot, and tar spot. A new entry, IS-8283, resisted anthracnose, leafblight, rust, zonate leaf spot, sooty stripe, rough leaf spot, and oval leaf spot. At Manfredi (Argentina), entries were artificially inoculated with the bacterial leaf stripe pathogen, *Pseudomonas andropogoni* (E.F. Smith) Stapp, and with maize dwarf mosaic virus (MDMV). Six entries (IS-8283, E-35-1 (IS-18758), IS-3925, CS-3541, IS-7322, and ((CS-3541 x IN-15-2) IS-93271-16-1) resisted both diseases.

Multiple Disease Resistance

Sorghum is vulnerable to attack by more than one disease at any location and season, so development of genotypes with resistance to several diseases is important. Development of effective and reliable resistance-screening techniques for grain mold and sorghum downy mildew, and using hot-spot locations for rust and anthracnose has enabled us to identify six sorghum genotypes that resist three or four of those diseases (Table 8). These genotypes are valuable sources of multiple disease resistance in breeding programs. The stability of resistance and additional diseases they resist will be further tested in our international sorghum disease resistance testing program.

Striga

Resistance screening techniques. Lack of a reliable field-screening technique has slowed progress on developing Striga-resistant sorghums.

At ICRISAT, we developed a three-stage, Striga-screening technique that we use in developing improved sorghum varieties that resist *Striga.* The technique accounts for *Striga* infestation variability by providing frequently repeated plots of a Striga-susceptible cultivar and increasing its frequency as tested material is moved through three stages: an observation nursery, a preliminary screening nursery, and an advanced screening nursery (Fig. 5).

Specific field layouts and statistical analytical procedures have been developed for the three stages. A checkerboard layout is deployed in the advanced screening stage to confirm resistance of the most resistant lines from the preliminary screening nursery.

A 'seed-pan' technique that we developed helps us screen individual plants for *Striga* resistance when sorghum seedlings are 55 days old. We are refining the seed-pan technique to reduce the days required and to make the technique nondestructive.

Breeding for resistance. Fifteen breeding lines and 5 source lines resistant to *Striga* in previous

Table 8. Disease ratings of sorghum lines resistant to sorghum downy mildew, anthracnose, rust, and/or grain mold.

			Diseases and rating[1]			
IS no.	Pedigree	Origin	Sorghum downy mildew[2]	Anthracnose[1]	Rust[2]	Grain mold[4]
3547	Rapbol	Sudan	1	2	1	2
2333	MN 971 Nyakina Q2/7/23	USA	1	2	2	3
17141	Bomkum	Nigeria	.5	2	1	2
21599	Misale	Malawi		2	2	2
8283	EC 21484 W5	India	1	2	2	5
2058	SA 8478-3 (DD)	USA	1	(	2	5

1. 1 and 2 resistant; 3 intermediate, 4 and 5 susceptible.
2. From field screening at Dharwar, 1982.
3. From field screening at Pantnagar, 1982.
4. From field screening at ICRISAT Center and Bhavanisagar, 1981 and 1982.
5. Not tested.

years' testing were tested in a checkerboard layout during the 1981 rainy season. Data from Akola, Bhavanisagar, and Bijapur confirmed that SAR-1, SAR-2, SAR-5, and SAR-6 carried useful field resistance to *Striga.* Another set of 160 breeding lines and 53 germplasm source lines, field tested in different trials in the preliminary screening layout, provided 8 breeding lines with good field resistance for advanced stage testing.

During the 1982 rainy season, 170 new breeding lines and 48 source lines were tested in the preliminary screening stage in *Striga-sick* fields at various locations in India; 55 lines that

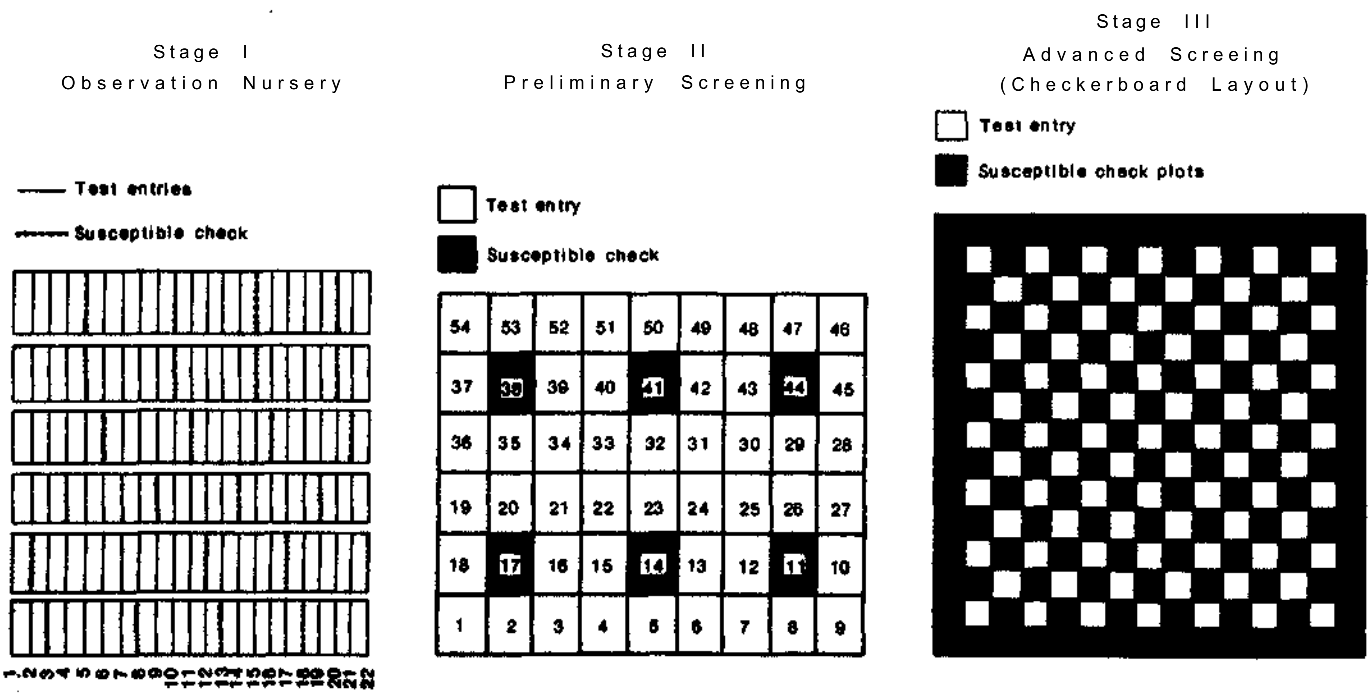

Figure 5. Three-stage screening for *Striga* resistance breeding in sorghum.

An ICRISAT scientist observes Striga-*resistant sorghum (background) sown on dryland in the post-rainy season at Bijapur, Karnataka, India; another points to a susceptible line.*

showed good field resistance to *S. asiatica* were retained for retesting; 15 breeding lines and 5 source lines were tested in multilocational trials in the checkerboard layout. Among source lines, N-13 was the best for *Striga* resistance (0.9% *Striga* plants compared with 100 percent in CSH-1 control plots).

Among the breeding lines, SAR-1, SAR-10, and SAR-13 had low *Striga* counts. Their individual reactions were 1.97, 1.71, and 2.04% of CSH-1.

Among several Striga-resistant lines evaluated at ICRISAT Center and Dharwar in *Striga*-free conditions to assess yield potentials, SAR-1 and SAR-12 yielded more than the improved released commercial varieties in India. Yields of the 15 breeding lines and 5 source lines also were assessed in *Striga-sick* conditions. Data from five locations (Table 9) revealed that CSH-1 yields in the *Striga-sick* plots varied from location to location. At all locations, however, the correlation coefficient (r) between CSH-1 yield and *Striga* counts was always negative and significant. Coefficient of determination (R^2) values indicated that only 10 to 33% of CSH-I's yield variation was explained by variation in *Striga* count. SAR-1, 2, 10, 13, and 15 yielded more than the susceptible control, CSH-1, in *Striga-sick* plots.

Physical Environment

Drought

A new study on environmental factors that control leaf-area development was initiated. Investigated were temperature, drought, and nitrogen effects on leaf emergence, expansion, and senescence.

Growth of sorghum (hybrid CSH-8R) grown on a Vertisol during the postrainy season under two levels of nitrogen and water was affected more by nitrogen than water (Fig. 6). With 230 mm of available water at sowing and evaporation only 4 mm/day, the dry treatment suffered only a mild drought stress near the end of the season. On the other hand, nitrogen was severely limiting; the profile content of NO_3- N was about 13 kg/ha to 120 cm deep.

Under adequate nitrogen and water (N+ W+) plants produced an average of 15 leaves and flowered in 67 days. Nitrogen stress with or without drought stress reduced the number of leaves by one, and delayed flowering by 12 (W-) and 9 (W+) days, but drought stress and nitrogen stress hastened maturity by 6 days. Emergence and expansion of individual leaves also were delayed. Senescence was hastened more rapidly under nitrogen stress than under drought stress.

Leaf extension rates (LER) in all treatments varied with diurnal changes in air temperature (Fig. 7). and increased linearly as temperature increased (Fig. 8); the highest increase was with water and nitrogen adequate N+ W+ (0.26

Table 9. ***Striga*** **reactions (SR)[1] and grain yields (kg/ha) of 15 breeding lines and 5 source lines in multilocation testing (checkerboard layout, rainy season 1982).**

		ICRISAT Center		Akola		Indore		Parbhani		Bijapur		Mean	
Origin	Pedigree	SR	Grain yield	SR	Grain yield	SR	Grain yield	SR	Grain yield	SR	Grain yield	SR	Grain yield
SAR-1	(555 x 168)-1-1	0.1	3970	4.2	2280	0.2	1540	5.7	2250	1.4	2130	1.9	2430
SAR-2	(555 x 168)-16	0.5	3370	3.9	2590	1.3	1600	10.2	1960	1.8	2120	3.0	2330
SAR-5	(148 x 555)-1-2	0.7	3960	3.6	2470	12.4	990	6.2	1960	2.6	1530	4.2	2180
SAR-6	(148 x 555)-33-1-3	0.2	3680	3.2	2180	1.0	2130	13.3	2450	0.5	1910	3.0	2450
SAR-9	[SRN-4841 x (WABC x P-3)]-7-3	1.1	4840	1.5	1070	4.9	2350	4.0	2080	12.8	1420	4.1	2350
SAR-10	[555x(PDxCS-3541)-29-3]-5-2-1	0.5	4110	1.1	2580	0.6	2620	6.8	2620	0.8	2170	1.7	2500
SAR-11	(555 x Awash-1050)-2-2	2.2	1560	5.7	1780	11.1	820	11.5	1670	3.9	1730	6.0	1510
SAR-12	(SRN-4841xSPV-104)-17	4.1	3500	5.3	1040	8.8	2160	9.3	2210	8.3	1130	7.1	2010
SAR-13	(555 x 168)-1	0.8	4600	1.7	2270	1.1	1730	5.6	1960	2.1	1600	2.0	2430
SAR-14	(Framida x 148)-21-2-2-4	0.3	4370	4.7	1070	13.0	710	3.8	2120	1.7	1300	3.9	1910
SAR-15	(555 x 168)-23-2-2-3-2	0.8	4210	5.0	2400	4.6	1760	28.6	1710	1.3	2140	6.9	2440
SAR-16	(555 x 168)-19-2-7	0.8	4340	5.2	2700	18.2	660	8.7	2450	2.3	1500	6.4	2330
SAR-17	(N-13 x 269)-5-2	3.2	2660	10.3	2210	10.1	860	2.6	2000	6.2	1710	5.7	1890
SAR-18	(N-13 x 2KX6)-1-2-1-2	3.2	4210	20.9	1670	4.2	9890	9.9	2080	11.7	1130	8.7	2020
T-233B	T-233B	128.1	2360	141.3	1660	156.9	710	31.1	1870	23.5	780	85.6	1470
N-13	N-13	0.1	1290	0.3	2190	1.1	770	2.9	1370	0.8	2850	0.9	1690
555	555	4.9	1170	10.3	2530	10.3	1030	4.0	1710	1.2	2150	5.2	1720
SRN-4841	SRN-4841	11.4	2210	6.8	-	10.3	1280	11.0	460	22.7	1230	10.5	1040
IS-4202	IS-4202	0.2	1690	3.8	2220	1.4	1970	4.3	1920	2.9	860	2.1	1730
IS-7471	IS-7471	0.8	-	12.9	-	25.5	-	9.5	-	0.9	1638	8.4	330
CSH-1[2]	Mean	230	4040	67	1310	222	1470	36	2130	501	800		
(suscep-	Min	82		7		4		13		189			
tible	Max	434		380		1047		101		817			
control)	'r'[3]		-0.43**		-0.49**		-0.57**		-0.39*		-0.32*		

1. SR of test entries = emerged *Striga* counts as percentage of control averaged over two replications.
2. SR of CSH-1 = emerged *Striga*/m^2 averaged over 40 CSH-1 plots in the checkerboard. Yield of CSH-1 also averaged over 40 plots.
3. *r* correlation between *Striga* count and yield/plot.

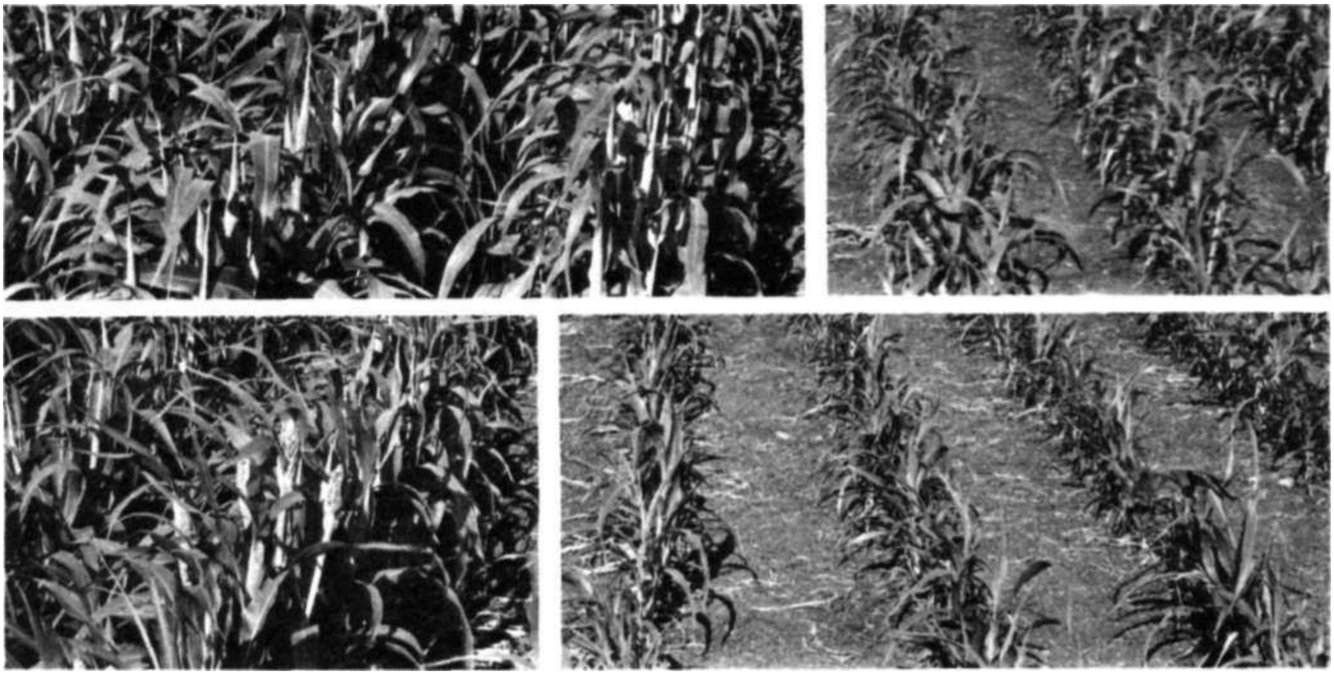

Figure 6. Effects of nitrogen and water on sorghum development 60 days after sowing: top left, 80 kg N/ha and irrigated; top right, no nitrogen but irrigated; bottom left, 80 kg N/ha but not irrigated; bottom right, no nitrogen or irrigation. ICRISAT scientists are breeding earlier-maturing sorghums to escape drought stress late in the season.

mm/hr per °C). LER was reduced by nitrogen and drought stress, which when combined synergistically reduced LER (Fig. 8).

Nitrogen stress reduced leaf area index and leaf area duration more than drought stress (Table 10). The reduced grain and dry matter yields were related primarily to reduced leal area duration (Fig. 9). During the postrainy season when the Vertisol profile is fully charged with moisture at planting, nitrogen stress is the major yield limiting factor; together with drought stress, nitrogen stress reduces grain yields even more.

High sensitivity of different components of leaf area to environmental stress emphasizes the need to screen for useful genetic variation for traits to use in developing plants better adapted to soil nitrogen and water supply.

Breeding for Resistance

A plant may suffer drought stress any time during its development. Its growth is frequently divided into three stages: GS1, from germination to floral initiation; GS2. from floral initiation to flowering; and GS3, from flowering to maturity.

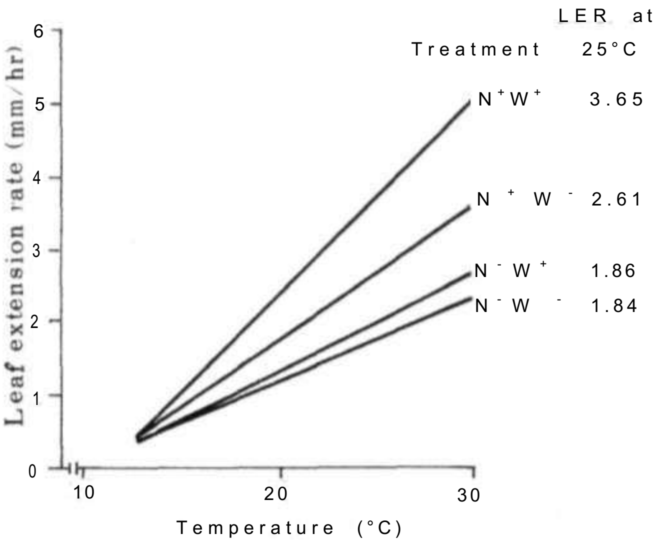

Figure 8. Relationships between air temperature and leaf extension rates (LER). All linear regressions were highly significant (P 0.01), ICRISAT Center, postrainy season 1981/82.

We conducted stress experiments at several locations in India where rainfall patterns and soil types varied. Sowing on deep black soils at ICRISAT Center suffered mild stress in the GS3; a sowing in similar conditions at Dharwar suffered two stress periods, GS1 and the end of GS2 into GS3. At Anantapur, where sowings were made on shallow red soils during the rainy season, the crop experienced prolonged, severe stress in GS1 stage. At Bhavanisagar, where the crop was on red soil, a gap in rains produced GS2 stress. At ICRISAT Center, screening during summer season was initiated by establishing the crop with irrigation.

Nurseries. Individual plant selection based on head size, grain characteristics, and plant type practiced in the nurseries grown at ICRISAT Center produced 260 F_3s, 174 F_4s, 46 F_5s, and 10 advanced generation lines. In addition a com-

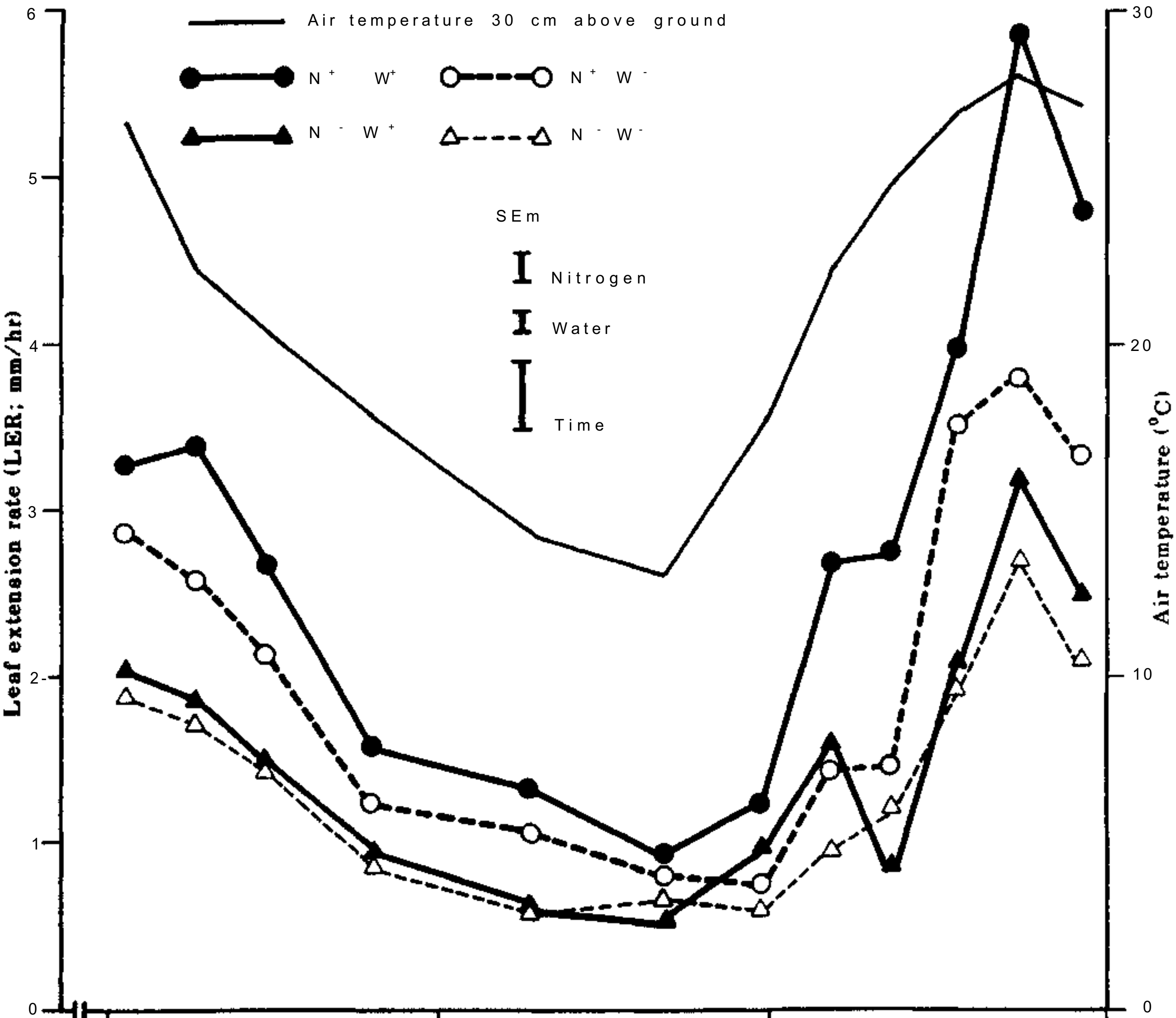

Figure 7. Diurnal variation in leaf extension rates (LER) and air temperature 40 days after sowing, ICRISAT Center, postrainy season 1981/82.

mon set of 75 entries evaluated at Anantapur and ICRISAT Center produced 40 and 60 F4 selections, respectively.

Screening. The genotypes were screened periodically to determine wilting rates. The recovery score represents how well an entry recovers from drought stress. In dry seasons, irrigation water to evaluate recovery can be applied after most entries have reached nearly complete desiccation.

We sowed a screening nursery of 126 lines in four replications at Anantapur and Bhavanisagar during the rainy season and at ICRISAT during summer. Twelve lines were superior for resistance to wilting, 11 for recovery, and 3 (D71283, D71406, and D38124) were superior for both traits. The other entries with good scores against wilting were D38001, D38129, D38119, D38380, D38131, D38095, D38200, D38009, and D71395 and for recovery, D38033, D38017, D38018, D38016, D38098, D38331, D38258, and D71464.

Correlations between the sets of recovery scores taken at Anantapur and Bhavanisagar,

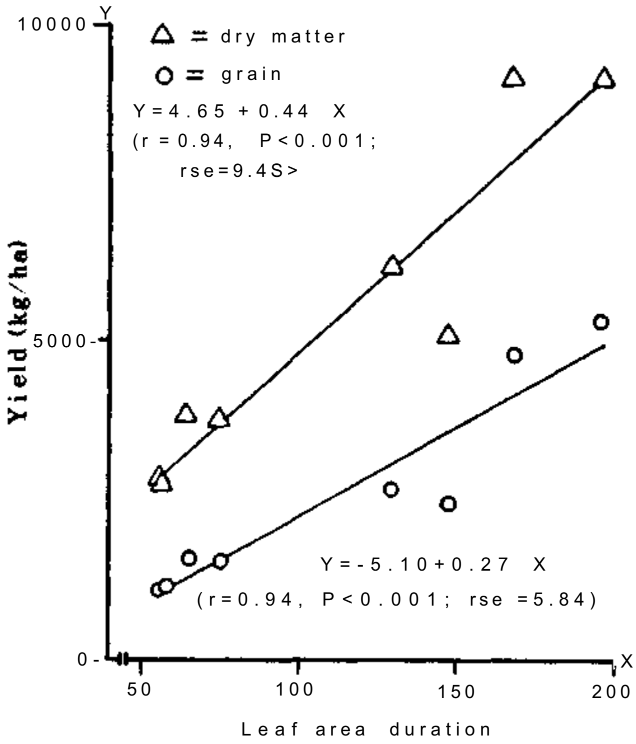

Figure 9. Relationships between leaf area duration (LAI days) and grain and dry-matter yields, ICRISAT Center, postrainy season 1981/82.

Table 10. Effects of nitrogen and irrigation treatments on leaf-area duration (LAD), seasonal total radiation interception, and grain and dry-matter yields[1], ICRISAT Center, postrainy season 1981/82.

Treatment	LAD			Radiation interception (mJ/m^2)			Grain yield (t/ha)			Total dry matter (t/ha)		
Irrigation →	W+	W-	Mean	W+	W-	Mean	W+	W-	Mean	W+	W-	Mean
With nitrogen	182	138	160	949	902	926	5.0	2.5	3.8	9.1	5.6	7.4
Without nitrogen	69	55	62	630	487	559	1.5	1.1	1.3	3.8	2.8	3.3
Mean	126	97		790	695		3.3	1.8		6.5	4.2	
SE	±3.5		±8.8	±17.7		±10.1	±0.19		±0.06	±0.26		±0.26
SE for comparing 2 irrigation treatment means with the same nitrogen	±5.0			±25.0			±0.26			±0.37		
SE for comparing 2 nitrogen treatment means with the same or different level of nitrogen	±9.5			±20.3			±0.20			±0.37		

1. LAD was computed by integrating the leaf area index (LAI) measured at 10-day intervals on an area of $0.75 m^2$. Plot size for final harvest is $27 m^2$.

Table 11. Performance of selected sorghum varieties at four locations and their drought symptoms at one location, 1982.

		Grain yield (kg/ha)					Anantapur	
Origin	Pedigree	ICRISAT Center	Dharwar	Anantapur	Bhavani-sagar	Mean	Recovery	Wilting[a]
D38033	(SPV105xSwarna)-1-1B	6470	6970	500	480	3600	2.3	1.5
D38028	(E36-1xDH-547-77R)-34-1B	5800	6720	340	600	3360	3.2	2.2
D38017	(2077BxSPV-86)-2-2B	4610	6850	320	480	3070	2.5	2.2
D38073	(20-67xSB1067)-4-1B	6080	5210	90	520	2970	3.0	1.8
D38077	(DH-521-77BxIS2328)-3-1B	5340	5530	350	590	2960	3.2	2.7
D38029	(SPV101xIS3541)-2-1B	5580	4930	460	1110	3020	3.4	2.4
D38060	(B.Y.C_3S_4xE35-1)-7-1B	4920	4670	410	1090	2770	2.6	2.5
D38127	(DH-519xE36-1)-5-1B	2760	4450	440	910	2140	3.2	2.1
D38092	(M35-1xM1049)-14-1B	740	4760	470	870	1710	3.8	2.7
D38130	(SB1067x22-40)-1-1B	4280	5210	450	870	2700	2.8	1.8
D38035	(IS2391xDJ1195)-2-1B	4460	4710	630	490	2570	2.8	3.1
Controls	CSH5	3860	5440	540	1400	2810	2.7	2.0
	CSV4	4810	4270	220	430	2430	2.5	1.8
	DJ 1195	5380	4790	170	760	2780	2.2	1.8
CV (%)		8	6	30	31	-	16	21
SE		±301	±260	±88	±170	-	±0.4	±0.4
Site mean		4610	4970	360	680	-	2.9	2.3
Efficiency (%) of lattice design vs RCB		101	100	115	127	-	111	101

a. 1 = least wilted or most recovered. 5 = most wilted or least recovered.

and those at ICRISAT Center (1982 summer) were not high owing to variations in drought stress interactions experienced at different growth stages. The relationship of scores for wilting at Anantapur and ICRISAT Center was fair but not related to scores from Bhavanisagar. This study suggests the need to initiate and terminate stress uniformly across locations to improve the efficiency of the screening procedure. Recoveries of D71283, D71406, and D71464 were consistent across locations and seasons.

Varietal yield trials. We evaluated 72 experimental varieties in preliminary trials at ICRISAT Center and Anantapur during the rainy season. Yields ranged from 4075 to 6470 kg/ha at ICRISAT Center (yield potential environment); from 130 to 890 kg/ha at Anantapur (drought environment). Genotypes ranked differently in both environments and the ranks at individual locations differed also from overall averages, indicating that the wide adaptability measure cannot identify genotypes for drought-prone locations. At Anantapur. D38064, D38133, and D38236 yielded significantly more than the drought resistant checks.

Performances of 36 advanced varieties evaluated in a triple-lattice design at ICRISAT Center, Dharwar, Bhavanisagar, and Anantapur are presented in Table 11. The first five entries were selected for yield in yield potential environments (ICRISAT Center and Dharwar); the remaining six, for average deviation of yield weighted by site means in drought-prone environments (Anantapur and Bhavanisagar). The genotype ranks obtained by the three procedures (overall means, yield potential locations means, and drought-prone locations weighted average deviations) differed widely, suggesting that selection based on stability or yield potential may not help identify suitable genotypes for drought-prone locations.

Correlations for grain yield among locations, drought symptoms, and agronomic traits showed drought symptoms—wilting and recovery—positively correlated with yield under drought stress, indicating that both traits are important in breeding. Height at yield-potential environment was related to yield under drought stress, suggesting that higher growth rate under yield-potential environment may help in selecting genotypes for drought-prone environments.

Entries D38060, D38077, D38127, D38084, and D38130 are resistant to rust; D38077, D38029, D38073, D38060, D38035, and 38092 were selected for emergence at 45°C soil temperatures.

Crop Establishment

Screening technique for resistance to high soil temperature. Poor crop stands limit sorghum yields in the SAT, and high soil-surface temperatures reduce seedling emergence, so we developed a technique to study seedling-emergence response to high soil temperatures with no drought stress.

With the technique, you keep long clay pots (30 cm) filled with sieved Alfisol in a water tank (Fig. 10), sow seeds 50 mm deep in each pot, heat the soil surface with a bank of infrared lamps fitted on a frame above the water tank. You can maintain a temperature of 35 to 50°C 20mm deep by varying the height of the lamps, and

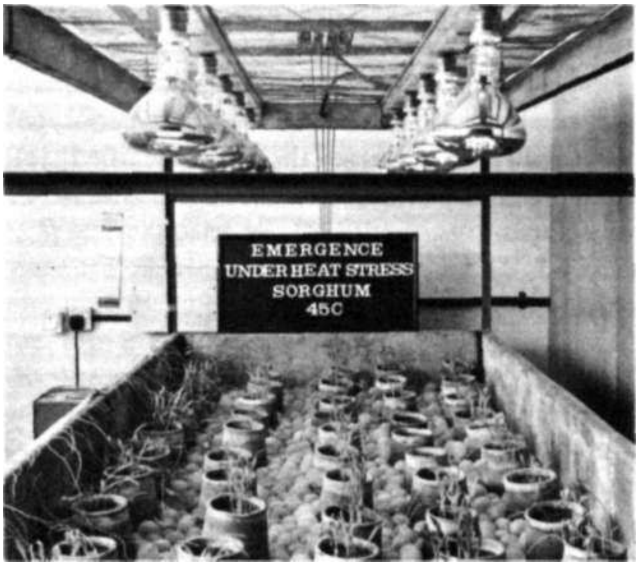

Figure 10. Infrared heater system used to screen for plant emergence at desired soil temperatures (representative of SAT) that reduce plant emergence and yields.

reach the temperature that you desire at 20 mm depth within 6 hr. Monitor the temperature with thermocouples and keep the soil heated until plant emergence stops (6-7 days from sowing). Sufficient moisture will remain as water is supplied through capillary movement through the wall of the pot. Maintain the test temperature (45°C), developed at 1400 hr, for about 3 hr.

Maximum soil-surface temperature in the field is reached most days between 1400 and 1500 hr.

Seeds of varieties we used were produced in the 1981 postrainy season.

Genotypic differences in emergence were most evident at 45°C. More than 75% of IS-1037, IS-2282, and CSV5 emerged while IS-2146, IS-4817, IS-83, and 1S-2705 failed to emerge; an intermediary group with 40 to 60% emergence was also identified.

Using the heated-soil technique, we screened another 34 elite lines from the drought project produced during the 1982 postrainy season, in a replicated trial with two checks, IS-1037 (good emergence) and CSH-6 (low emergence) under 40, 45, and 50°C. The effects of temperature, genotype, and temperature x genotype interactions were highly significant ($P<0.01$). At 45°C, 26% of the entries did not emerge, 29% showed less than 50% emergence, and 38%, more than 60% emergence.

So the technique, by simulating soil temperatures in the field, can be used to screen genotypes for ability to emerge through specified soil temperatures under no drought stress or crusting.

Postrainy Season Adaptation

Postrainy-season sorghums, which grow on about 1/3 of India's sorghum acreage, usually are sown in October and develop in shorter, cooler days when soil moisture is receding. Drought stress toward crop maturity is common.

Developing breeding lines.— As part of an effort to diversify sorghum's genetic base for breeding, we used known postrainy season Indian lines and selected lines from Nigeria, Sudan, Niger, Benin, Kenya, Ethiopia, Malawi, and USA as parents in crossing. Evaluations of the breeding materials were carried out at ICRISAT Center (17°30'N) and Bijapur (16°45'N) by sowing after mid-September on black soils. The crop grew well initially, but cold temperatures coupled with depleted available moisture when grain was developing caused severe loss of green leaf area and lodging.

We selected 697 F_3s, 128 F_4s, 56 F_5s, and 47 $F_6/_7$s at ICRISAT Center and 330 F_3s at Bijapur for further evaluation.

Evaluating varieties. We evaluated 133 breeding lines in three preliminary yield trials at ICRISAT Center and advanced 9 lines for further testing based on grain yield, lodging, plant height, and days to flowering.

The advanced yield trial of 36 entries was sown 9 September at Bijapur; 15 September and 13 November at ICRISAT Center. The September-sown trials were rainfed. The late-sown trial got one supplemental irrigation in addition to a presowing one. Twelve lines (D83325, D71240, D82792, D71258, D83336, D82072, D71383, D84049, D71185, D82081, D71680, and D12417) substantially outyielded the check variety M35-1. They matured earlier or at the same time as the check, were similar or shorter in plant height, and generally lodged less than the check.

M35-1 sorghum variety is widely grown in the postrainy season; to escape terminal drought stress, varieties that flower earlier than M35-1 are needed—10 of the 12 selected varieties satisfy that objective, and most of them significantly outyielded M35-1 (2230 to 3025 kg/ha vs 1905 kg/ha). Sorghum lines planted late flowered from 1 to 15 days later than those planted early.

In a trial of 50 advanced entries from improved populations at ICRISAT Center, 4 entries yielded more than CSV-8R. Only 7 of the 50 entries were advanced for testing in 1983 postrainy season—A6306, A1010, A5380, A1009, A1075, A1033, and A1008.

In another trial of 25 preliminary varieties at ICRISAT Center, 6 entries yielded more than

Promising sorghum varieties for the post rainy season being inspected at Bijapur, Karnataka, where ICRISAT works in cooperation with the University of Agricultural Sciences. Postrainy-season sorghums occupy one-third of India's total sorghum-growing area.

CSH-8R and 16 yielded more than CSV-8R, the control. All 16 were selected for further testing next year.

Four varieties, D71240 (SPV-578), D12417 (SPV-579), D71383 (SPV-580) and D82792 (SPV-581) were entered in the regional postrainy-season trial of the All India Coordinated Sorghum Improvement Project.

Evaluating hybrids. Of 85 hybrids evaluated in a nursery, 20 were selected for further testing.

A trial for the postrainy season was organized using 36A (the seed parent for CSH-8R) as the seed parent. The most promising eight hybrids are: 36A x D24036, 36A x D24254, D36A x D24261, 36A x D24242, 36A x D24037, 36A x D24302, 36A x D24241, and 36A x D24245. Each of the eight hybrids yielded more than M35-1 and two of them (36A x D24037 and 36A x D24254) yielded 36% more than the hybrid control, CSH-8R (3406 kg/ha). Most of the eight lodged less than CSH-8R or M35-1.

Another trial consisting of 40 hybrids was also conducted during the 1981 postrainy season at ICRISAT Center. Promising hybrids were 296A x SPV-422, 296A x A740, 296A x A6636, 296A x A505, 2077A x A909, 2077A x A910, and 2077A x A916. One hybrid (296A x SPV-422) was identified for the AICSIP Trial in 1982. The remaining six hybrids will be tested once again at ICRISAT Center during the 1982/83 postrainy season.

Efforts are being made to diversify the seed parents available for producing hybrids suitable for postrainy season. The male-sterile line, D1 A, now at 6th backcross, has a thin stalk. It is taller than 36A and less susceptible to rust. In addition. 313 pairs are at the backcross 2 stage of development.

Nitrogen Fixation

Measuring Nitrogen Fixation

Using two systems of plant culture and gas handling, we exposed sorghum seedlings to nitrogen gas enriched with the stable isotope ^{15}N and demonstrated that nitrogen is fixed in the root zone and transferred to the tops of the plants. Initially we grew CSH-5 seedlings in a sand-farmyard manure (97:3 w/w) mixture in 25- x 200-mm test tubes with an attached side tube.

When exposed to $^{15}N_2$, the tops of the plants were sealed from the root system by a Suba Seal and silicone rubber sealant, and gas in the root medium in the test tubes was exchanged by water displacement. The oxygen content of the root zone was monitored and maintained at 20%.

After exposing 20-day-old CSH-5 seedlings to labeled nitrogen gas for 3 days, ^{15}N was detected in the growth medium (0.005 ^{15}N atom % excess). Seven days after the labeled gas was removed, the ^{15}N atom % excess in the plants increased considerably with 0.029 atom % excess in the roots and 0.019 atom % excess in the shoots.

We tested a device developed at Rothamsted Experimental Station, UK for gassing 10 plants at once. We grew CSH-5 plants for 24 days in 35 x 295 mm plastic tubes containing sand:FYM (97:3 w/w), then enclosed the root systems in the tubes with silicone rubber around the stem bases.

We replaced the gas in the root chamber by flushing with CO_2 then absorbing out the CO_2 over soda lime and allowing a $^{15}N_2$:O_2 mixture to be drawn in. We thus avoided flooding the root zone with water to transfer the gas. Table 12 shows that ^{15}N was incorporated in the shoot system by the end of the 3-day exposure period; ^{15}N incorporation in the leaves had further increased 9 days later.

Our results show unequivocally that nitrogen is fixed by bacteria in the rhizosphere of sorghum seedlings and is rapidly taken up by plant roots and that some is transferred to the shoot system.

Acetylene (C_2H_2) Reduction Assay

Soil core assay. We improved the soil core assay developed earlier (ICRISAT Annual Report 1975/76, pp. 85), and compared nitrogenase activity with nine genotypes of sorghum grown in Alfisol soil during the rainy season by using our assay of regular (disturbed) cores taken at the time of assay and a planted core assay where plants were grown with their roots enclosed by the core from 25 days after planting. Table 13 shows that significantly more activity was obtained with the planted core assay (535 nmol C_2H_4/ plant per hr) than with the regular core assay (35 nmol C_2H_4/ plant per hr). Similar differences were recorded in another experiment. Earlier results indicated that mechanical disturbance to the plant cores during handling reduced nitrogenase activity considerably (ICRISAT Annual Report 1981, p. 64).

Intact-plant assay for pot-grown plants. Factors affecting the intact-plant assay for estimating nitrogenase activity of pot-grown plants (ICRISAT Annual Report 1979/80, p. 41) were further studied.

Sorghum hybrid CSH-8 plants grew significantly better in pots filled with sand:FYM (97:3 w/w), or Alfisol soil than plants grown in vermiculite or sand:soil (60:40 w/w). Plants grown in sand:FYM had the most nitrogenase activity (Table 14).

Other studies comparing mixtures of sand and FYM showed that plants grew better with more nitrogenase activity as the amount of FYM mixed with the sand increased to 3%.

We studied root temperature effects on nitrogenase activity by growing plants in plastic containers conditioned at a particular temperature (controlled by water baths) for 10 days before the assay. More activity was obtained at 40°C and 34°C (370 and 358 nmol C_2H_4/plant per hr) than at 29°C (195 nmol C_2H_4/plant per hr).

Table 12. $^{15}N_2$ incorporation by sorghum hybrid CSH-S seedlings.

	Time of harvest after exposure to $^{15}N_2$			
	0 days		9 days	
	Shoot	Root	Shoot	Root
Dry weight (mg/plant)	264	246	400	673
^{15}N atom % excess	0.056	0.059	0.102	0.073
^{15}N incorporated (µg/plant)	15.9		25.5	

Average of 3 replications; plants grown in 35-N 295-mm plastic tubes filled with sand:FYM (97:3 w/w); 24-day-old seedlings exposed to $^{15}N_2$ (40 atom % excess) for 3 days. Data from collaborative project with Rothamsted Experimental Station funded by the UK Overseas Development Administration.

Table 13. Nitrogenase activity of sorghum lines estimated by regular core and planted core assay methods.

Cultivar	Nitrogenase activity (nmoles C_2H_4/plant per hr)[a] Regular core assay	Planted core assay
IS-1057	24	2101
IS-2207	41	253
IS-9180	33	295
IS-2638	33	316
IS-2391	38	682
IS-3951	37	448
1S-3949	30	267
CSV-5	61	335
Soil	20	119
Mean	35b	535c

[a]. Average of 4 replicated cores. Log transformation (nmoles C_2H_4+1) used to analyze data. Figures with different letters vary significantly ($P<0.05$) from each other.
Plants grown in an Alfisol field during the rainy season; assayed for nitrogenase activity 63 days after planting.

Table 14. Growth and nitrogenase activity of sorghum hybrid CSH-8 in indicated media.

Media	Nitrogenase activity (nmoles C_2H_4/ plant per hr)[a]	Plant dry matter (g/plant)
Soil (Alfisol)	7b	40
Vermiculite	49 d	35
Sand:Soil (60:40 w/w)	22 c	24
Sand: Farmyard Manure (97:3 w/w)	270 c	43
SE		±1.5
cv %		20

[a]. Average of 15 replications. Log transformation (nmoles C_2H_4+1) used to analyze data. Figures with different letters vary significantly ($P<0.05$) from each other.
Plants were grown in 7 liter capacity plastic pots with equivalent of 20 kg N/ha added as ammonium sulphate, nitrogenase activity estimated at 50 days after planting (DAP) and plants harvested at 66 DAP.

We compared the nitrogenase activity of 15 lines of sorghum using two assay systems, growing plants in pots, then assaying them as intact plants (see ICRISAT Annual Report 1979/1980, p. 41) or exposing the soil-root systems in the pots to acetylene after cutting off plant tops. Intact plants had significantly more activity than the plants with tops removed (Table 15), particularly 76-day-old plants. The intact plants averaged 291 nmol C_2H_4/plant per hr and decapitated plants, only 11 nmol, a 26-fold difference. Activity was greater at the 49-day assay than at the 76-day assay, and three of the four highest yielding sorghum lines were also in the top five ranking cultivars at the 76-day assay.

Table 15. Nitrogenase activity of intact and decapitated sorghum plants.

Cultivar	Nitrogenase activity (nmoles C_2H_4/ plant per hr)[a] Intact-plant assay	Decapitated-plant assay
1S-84	3590	1910
CSV-5	3060	1370
1S-1256	1650	26
IS-5108	480	80
Dobbs	370	16
IS-2261	290	30
2077 B	190	270
IS-2190	66	17
IS-1324	60	40
IS-2267	50	47
IS-2980	40	33
1S-801	32	35
IS-2207	30	15
IS-1398	26	18
IS-5218	26	18
Soil	13	27
Mean	625 b	247 c

abc. Average of 5 replications. Log transformation (nmoles C_2H_4+1) used to analyze data. Figures with different letters vary significantly ($P<0.01$) from each other.
49-day-old plants grown in 6-liter plastic containers filled with Alfisol soil, assayed for nitrogenase activity; plants decapitated just before the assay.

Response to Inoculation

A field trial was conducted during the 1982 rainy season on an Alfisol with the three sorghum hybrids CSH-1, CSH-5, and CSH-9 inoculated with different nitrogen-fixing bacteria at sowing and again just after seedlings emerged. A randomized-block design was used. Inoculating with *Azospirillum lipoferum* and a root extract from Napier bajra increased dry-matter production ($P<0.10$) of the three hybrids taken together (Table 16). The trend toward increased grain yield from inoculation was not statistically significant.

Nitrogen-fixing Blue Green Algae

We surveyed several fields throughout the year for nitrogen-fixing blue green algae (cyanobacteria). The predominant heterocystous algae, seen forming mats on several fields, were two *Anabaena* species and *Nostoc muscorum.* Other *Nostoc* species were observed as well as algae belonging to the following genera: *Calothrix, Aphanothece, Microcystis, Lyngbya,* and *Oscillatoria.*

The nitrogen-fixing activity (C_2H_2 reduction) of the algae-formed mats depended on soil moisture, light, and temperature. Maximum activity was in early afternoon. Activity as high as 1.6 nmol C_2H_4/core per hr (4.3 mg N/m^2 per hr) was observed in one Alfisol field cropped to sorghum in the rainy season. To estimate the blue-green algal contribution to nitrogen balance, we took many cores throughout the field several times during the season. Average activities for a given afternoon ranged from 1 mg N/m^2 per hr to nearly zero when the soil surface became very dry.

Root Exudates and Growth of Nitrogen-fixing Bacteria

We found significant differences in amounts and patterns of organic carbon exuded into culture media by seedling roots of six sorghum cultivars grown in axenic liquid culture. Sorghum genotypes that exuded the most organic carbon supported the most nitrogenase activity by an *Azospirillum lipoferum* inoculum.

Monitoring growth and nitrogenase activity of five bacterial strains in semisolid synthetic media, containing root exudates from three sorghum genotypes as the sole organic carbon source, showed significant ($P<0.05$) differences in growth and activity between bacteria and

Table 16. Effect of inoculating three sorghum hybrids with nitrogen fixing bacteria on dry-matter production, ICRISAT Center, rainy season 1982.

		Total dry matter (kg/ha)			
Inoculum	Cultivar	CSH-1	CSH-5	CSH-9	Mean
Azospirillum lipoferum (1)		7380	11210	10030	9540
Azospirillum lipoferum (2)		7860	9820	11150	9610
Napier bajra root extract		6930	11360	10220	9500
Azotobacter chroococcum		7420	7600	9740	8260
Uninoculated		7000	8110	8670	7920
SE			±820		±379
Mean		7320	9620	9960	
SE			±198		
CV%			21		

Average of 4 replications, net plot size 13.5 m^2. Urea fertilizer at 20 kg N/ha banded as top dressing.

Table 17. Vesicular Arbuscular Mycorrhizal (VAM) inoculation, plant dry-matter production, and Phosphorus in xylem exudate of sorghum hybrid CSH 5.

Cultures	Percent colonization	Shoot dry matter[a] (g/plant)	Pi in xylem exudate[b] Conc. (µg/ml)	Pi in xylem exudate[b] Total (µg/plant)
Glomus fasciculatum	66(8.1)[c]	1.93	83	25
Glomus mosseae	52(7.2)	2.20	59	18
Gigaspora margarita	48(6.9)	2.07	50	23
Glomus fasciculatum E3	40(6.3)	1.43	77	17
Gigaspora calospora	36(6.0)	1.14	28	7
Acaulospora laevis	32(5.6)	1.33	40	13
Control	25(5.0)	0.98	20	5
SE	±(0.32)	±0.15	±5	±3
CV (%)	11	21	21	45

a. 54-day old plants. All values means of 5 replicate pots each with 1 plant grown in 1.1 v/v sand:Alfisol soil mixture, steam sterilized before sowing. Mycorrhizal inoculation at sowing with infected root segments of *Panicum maximum* containing approx. 600 extra-matrical spores per pot.

b. Pi = inorganic (or available) P determined by a vanadium molybdate method.

c. Figures in parentheses are data for per cent colonization analyzed after transformation as $\sqrt{x+0.5}$.

between exudate media. The bacteria x genotype interaction was significant, indicating qualitative differences in root exudates, which may be important in selecting bacteria for inoculation trials.

Mycorrhiza

A field survey at ICRISAT Center showed that sorghum forms vesicular arbuscular mycorrhizal (VAM) symbiotic associations with the four major genera of VAM fungi.

In a pot trial with a root medium of sterilized sand and Alfisol soil (1:1 v/v), inoculating sorghum cv CSH-5 with six species of VAM fungi increased growth 115 to 220%. VAM cultures varied widely in ability to stimulate sorghum growth (Table 17). There was a significant correlation between the proportion of the root colonized by VAM (log transformed data) and plant dry-matter production, based on the means for each strain ($r = 0.89$; $df = 6$; $P \leq 0.05$). However *Acaulospora* and *Glomus mosseae* did not follow this relationship.

Since, VAM fungi benefit the host plant by enhancing P uptake, we examined the P content of the xylem exudate. The percentage of VAM colonization and available P in the xylem exudate, measured by a vanadium molybdate method correlated significantly ($r = 0.64$; $df=34$; $P \leq 0.01$). That correlation suggests that P in the xylem exudate could be used to screen plants and VAM isolates for the effectiveness of the symbiosis they form. This technique needs more work to standardize exudate collection, and to account for the diurnal pattern of exudation and fluctuations in P concentrations in the exudate during plant growth.

Food Quality

Grain Sprouting

Grain weathering and head sprouting are common in sorghum heads exposed to rainfall in late growth stages. Sprout damage has been reported to induce alpha-amylase activity which modifies carbohydrates in the grains. Such damage, if extensive, would lower the quality of food prepared from the damaged grain (Tables 18 & 19).

We monitored the alpha-amylase activity in sorghum grains grown during the rainy season. Alpha-amylase activity expressed as specific activity (change in absorbance per mg protein) ranged from 0.19 to 0.48 in rain-affected grains but was less than 0.19 in dry-season harvests.

To study the effect of sprouting on flour and *roti* qualities, we soaked grain samples of 15 genotypes in distilled water for 4 hr then removed the samples and kept them in a germinator 30 hr at 35°C. We then subjected the control and laboratory-sprouted grain samples to alpha-amylase assays and flour quality evaluations.

The alpha-amylase activity of sprouted grains was high (mean 0.75). Average particle size and rolling quality of flour from sprouted samples were significantly lower than from controls. Particle size of the flour from sprouted grain was reduced 20 to 30%. Rolling quality of flour from the sprouted grains of two cultivars did not differ significantly from that of controls, perhaps because germination of these lots was only 50%. Spreading quality of gel made from sprouted samples differed significantly from that of controls; gel from sprouted samples was thin, less firm, and visually poor. Taste and keeping quality of roti made from sprouted samples was significantly below those factors of roti from control samples.

Grain Characteristics

Endosperm texture or hardness of the grain is associated with its quality as food. We compared

Table 18. Properties for some grain- and flour-quality attributes of 15 sorghum cultivars.

	Flour[1]							
	α-amylase activity		Rolling quality (cm)		Flour over 125μ (%)		Flour thru 75μ (%)	
Genotype	C	S	C	S	C	S	C	S
M35-1	0.15	0.74	24.2	21.6	12.4	12.8	66.1	67.8
IS 10504	0.20	0.54	16.0	17.1	12.3	6.4	73.7	83.3
SPV 351	0.17	0.80	22.2	19.7	22.5	14.5	48.4	62.9
SPV 475	0.19	0.80	23.7	21.5	24.0	19.7	43.9	53.1
CSH-1	0.13	0.67	23.7	21.5	21.3	16.6	53.5	61.5
CSH-4	0.15	0.77	22.5	21.2	18.5	21.8	52.2	50.2
2077B	0.14	0.66	23.5	17.4	13.7	10.1	64.9	72.8
CS 3541	0.17	0.68	22.4	17.7	30.0	18.5	39.4	52.9
Mothi	0.14	0.66	23.5	20.2	29.5	19.4	41.3	54.5
Safra	0.16	0.64	23.5	17.2	21.7	9.8	53.1	70.9
SPV 352	0.15	0.62	23.7	19.1	24.1	18.4	47.9	54.8
CSH-9	0.14	0.81	23.2	19.1	29.0	15.0	44.4	62.8
CSH-5	0.15	0.82	22.0	19.2	35.9	11.8	59.2	69.1
CSH-8	0.14	0.81	24.7	20.7	14.0	10.9	63.8	69.4
E6954	0.11	0.66	25.5	20.5	26.1	19.2	42.5	57.2
Mean	0.15	0.75	23.0	19.6	22.3	15.0	52.9	62.9
SE ±	0.01	0.08	0.55	0.42	1.85	1.17	2.70	2.40

1. Values are averages of two observations.
C = Normal control grains.
S = Grains sprouted for 30 hours.

Table 19. Properties for some food-quality attributes of 15 sorghum cultivars.

	Flour		Roti[1]			
	Gel Spread (mm)		Taste		Keeping quality	
Genotype	C	S	C	S	C	S
M35-1	57	57	2.0	2.5	2.0	2.5
IS 10504	73	94	3.0	4.0	3.0	4.0
SPV 351	58	62	2.5	3.0	2.5	2.7
SPV 475	55	57	2.7	3.0	2.5	2.7
CSH-1	57	57	2.7	3.0	2.5	2.5
CSH-6	58	62	2.5	3.5	2.7	3.2
2077 B	58	58	2.7	4.0	2.7	3.7
CS 3541	56	57	2.7	3.5	2.7	3.2
Mothi	59	64	2.5	3.7	2.7	3.7
Safra	61	70	3.0	3.7	3.0	4.0
SPV 352	59	63	3.0	3.5	3.0	3.0
CSH-9	61	64	2.5	3.0	2.7	3.0
CSH-5	60	64	2.2	3.0	2.2	2.5
CSH-8	56	55	2.8	3.5	2.5	2.0
E6954	56	58	3.0	4.0	2.5	2.7
Mean	59	63	2.6	3.4	2.6	3.1
SE ±	1.1	2.5				

1. Roti taste and keeping quality rated on 1 to 5 scale; 1 - good and 5 = unacceptable.
C = Normal control grains.
S = Grains sprouted for 30 hours.

several methods to describe grain hardness of bulk samples from 15 white-seeded cultivars that lacked testa but had diverse endosperm properties.

Our replicated observations covered these grain attributes: (a) corneousness percentage, measured with a light microscope as the translucent area of the endosperm in a longitudinal section of the grain; (b) grain-breaking strength in kg measured with a Kiya Hardness Tester; (c) grain density; (d) the grain's water absorption estimated by soaking in water 5 hr at room temperature; (e) percentage of floaters in a sample of 100 grains placed in sodium nitrate solution of 1.3 specific gravity (adopted from Carlsberg Research Center, Copenhagen); (f) percentage of uniformly ground flour retained on 75- to 250-μ sieves.

Statistical analysis of the data showed highly significant differences among genotypes (Table 20). Most of the quality factors correlated negatively and highly significantly ($P < 0.01$) except percentage floaters vs flour through the 75-μ sieve. That correlation was positive ($r = 0.87$). Soft endosperm grains produced the finest flour.

Among the various methods used, breaking strength was affected by grain shape. Analysis of particle sizes showed that different milling and sieving techniques determine flour particle size. Mechanical sieve shakers cannot be used to determine particle size of fine flour because it agglomerates. Several workers have used grain's resistance to pearling as a measure of hardness. But grain size, shape, and pericarp structure affect that measurement. Pericarp structure also affects water absorption.

Table 20. Mean properties for indicated grain and flour quality attributes of 15 sorghum cultivars.[1]

Genotype	Corneous endosperm (%)	Breaking strength (kg)	Grain density (g/cc)	Floaters (%)	Water absorption (%)	Flour over 125 μ (%)	Flour through 75-μ sieve (%)
M35-1	32.5	5.7	1.25	55	16.5	9.1	74.4
2077B	49.2	4.1	1.21	72	23.6	8.9	72.4
IS 1401	4.0	4.3	1.22	93	21.0	7.5	80.9
IS 5604	48.1	5.0	1.26	19	18.3	24.7	49.2
CSH 6	50.1	6.1	1.30	10	22.5	20.6	48.0
E35-1	68.4	11.0	1.32	14	20.6	19.5	48.8
SPV 351	61.6	8.1	1.20	22	23.3	22.2	46.2
SPV 422	57.8	7.9	1.26	56	25.2	11.0	67.2
CSH 8	49.3	5.8	1.25	47	22.9	11.5	65.0
296B	48.1	6.3	1.22	50	21.2	12.9	65.9
2219 B	80.2	6.5	1.28	4	18.9	23.2	45.6
P-721	5.8	5.2	1.06	99	36.6	10.4	78.4
S-29	75.1	7.2	1.22	83	23.9	17.5	55.8
IS-9985	45.1	6.1	1.15	93	24.9	6.3	81.5
SPV 393	57.2	6.8	1.21	59	26.4	14.5	61.7
Mean	48.8	6.4	1.23	52	23.1	14.6	62.7
Maximum	80.2	11.0	1.32	99	36.6	24.7	81.5
Minimum	4.0	4.1	1.06	4.0	16.5	6.3	45.6
SE ±	1.17	0.13	0.004	1.02	0.43	0.32	0.47
CV (%)	27.8	7.9	1.4	7.6	2.6	8.6	2.8

1. Averages of three independent observations each replicated over three weeks; all genotypes have white pericarps.

We found percentage floaters in a 1.3 specific-gravity solution is a rapid, effective method to evaluate and classify many samples for grain hardness and endosperm texture into a small number of classes.

Pop Sorghum

Studying popping quality of 30 sorghum cultivars, we associated various grain quality characters with popped sorghum. The volume of a 5-g popped sample varied from 9 to 54 cc, and floaters varied from 12 to 99%. Starch granules in the endosperm of the 30 cultivars varied in size from 17 to 26μ. Floater percentage and pop volume correlated negatively (0.67 = P < 0.01). Starch granule size correlated negatively with pop volume (0.58 = P < 0.01).

In a preliminary study on the inheritance of popping quality, we used crosses between eight parents with varied levels of popping quality (volume) and found popping volume highly heritable and controlled by polygenes.

Population Improvement

Recurrent Selection

We continued recurrent selection in five sorghum populations: US/R, US/B, Rs/R, Rs/B, and West African Early (WAE). Indian Synthetic, the newly composited population, is ready for its first cycle of recurrent selection in 1983.

During the 1981 rainy season, 196 S_2 progenies from Rs/ R and Rs/ B populations, and four checks were evaluated at ICRISAT Center, Bhavanisagar, and Dharwar. Using their performance on several traits, we selected 38 S_2 progenies from each of Rs/ R (mean grain yield, 4292 kg/ha) and Rs/B (mean, 4830 kg/ha) and recombined them in the 1981/82 postrainy season, which completed the fourth cycle of recurrent selection. During recombination phase, sources of shoot fly and midge resistance were injected into the restorer populations; 12 additional nonrestorer lines were incorporated into the Rs/B population.

From Rs/R and Rs/B random-mating populations in cycle 4, we selected 4576 Rs/ R and 990 Rs/ B half-sib progenies and evaluated them in unreplicated nurseries during the 1982 rainy season; we used overall performance, including resistance to insects and diseases, of those progenies, and selected 397 S_1 of Rs/R and 990 S, of Rs/B progenies. They were advanced to S_2 progenies during the 1982/83 postrainy season.

The US/R and US/B populations are in their 5th selection cycle. Half-sib progenies from both populations (798 of US/R and 892 of US/B) were evaluated in the 1981 rainy season and 397 US/R and 413 US/B selected S_1 progenies were evaluated and advanced to S_2 progenies in unreplicated nurseries at ICRISAT Center in the 1981/82 postrainy season and at Bhavanisagar in 1982 summer. The 196 selected S_2 progenies from each population were evaluated in replicated trials at ICRISAT Center, Dharwar, and Bhavanisagar in the 1982 rainy season.

Using overall performances, we selected 41 S_2 progenies in US/R and 46 S_2 progenies in US/B to recombine to complete the 5th selection cycle. During recombination, 19 restorer and 14 nonrestorer lines with desirable characteristics will be incorporated, respectively, into US/R and US/B populations.

Population-derived Lines

We continued extracting lines from improved populations by advancing the generations of plants selected from different stages of population development. We grew 2105 derived lines in a nonreplicated nursery, and we advanced 762 lines. The most promising and uniform of them will be included in yield trials and other nurseries to evaluate resistances to various yield-limiting factors.

Varietal Trials

Two Preliminary Variety Trials, PVT-1 and PVT-2 (39 early- and 39 medium-maturity lines, population derived) were evaluated at ICRISAT Center, Dharwar, and Bhavanisagar. Eight selected lines in PVT-1 and 6 in PVT-2 yielded well at all locations. But most of them are taller and matured later than the hybrid check. Pedigrees of lines that yielded well and were selected for further evaluation and selection are: PVT-1— ICSV-101, A13152, A13153, A13121, ICSV-139, A13172, ICSV-134, and ICSV-136; PVT-2—ICSV-138, A13194, A13201, ICSV-105, A13239, and ICSV-104.

Evaluation of Advanced Elite Varieties

The evaluations of 60 varieties derived from the grain quality project at ICRISAT Center, Dharwar, and Bhavanisagar in 1981 and 1982 confirmed the superior yield and stability of M60252, M60256, and M60297. And we selected two new varieties (M60370, and M60396) for high grain yield, improving quality, and agronomic eliteness.

Also in 1982 we evaluated 33 improved varieties selected in 1981 for adaptation and yield stability at ICRISAT Center, Dharwar, and Bhavanisagar. At ICRISAT Center, they were evaluated in Vertisol and Alfisol under low and high fertility and sprayed and unsprayed environments (Table 21). Coefficient of variation was high in the low-fertility environments, from 23 to 47%.

The genotype x environment interaction was significant. But three varieties (ICSV-130, 120, and 138) had stable, high yields at most environments. ICSV-147, a *Striga asiatica-resistant* variety, was highest yielding under low fertility, but

Table 21. Mean grain yields (kg/ha) of indicated elite, advanced sorghum varieties evaluated at three sites in India, rainy season 1982 (RCB, three replications, plot size variable: 4 m^2 minimum, 12 m^2 maximum).

Varieties	Pedigree	Dharwar	Bhavani-sagar	ICRISAT Center HF[1] (2)[2]	ICRISAT Center LF[3] (3)[4]
ICSV-130	(22-40xSPV-105)-6-12-1-1-B	5630	3170	7160	2350
ICSV-120	[(148xE35-1)-4-1xCS-3541 deriv.]-5-3-2	6350	3080	5960	2160
ICSV-138	CSV-4xG.G.x370-2-1-1-4	7230	4920	6580	2060
ICSV-126	[SC-108-3xSwarna)xE35-1]-6-2	7940	4080	6050	1870
ICSV-139	UchV2xFLR-101-2-1	7870	1920	5860	1570
ICSV-114	[(SRN-4841 xWABCxP-3)-3]-7-3	5240	2210	5380	2310
ICSV-145	(555xGPR-168)-I-I	4370	960	4680	2200
ICSV-147	(555xGPR-168)-23-2-2-3-2	2420	2420	4530	2460
ICSV-115	(555xGPR-168)-19-2-7	1940	2830	4470	2120
ICSV-107	(SC-108-3xCS-3541)-19-I(SPV 351)	6540	2750	5230	2190
CSH-5	(Hybrid control)	6000	3290	6490	3060
SE		±390	±441		
CV(%)		11	31		

1. HF = High Fertility (128:82:0).
2. ICRISAT Center two locations: Vertisol SE ± 390, CV(%) 13; Alfisol SE ± 300, CV(%) 11.
3. LF = Low Fertility (40:20:0).
4. ICRISAT Center three locations: Alfisol SE ± 385, CV(%)28; (pesticide *free)* SE ± 372, CV(%)47; Vertisol (pesticide free) SE ± 225, CV(%) 23.

did not compete under high fertility at ICRISAT Center. All varieties were about 25% shorter and matured a week later under low fertility. Severe headbug damage, especially in later-maturing varieties, further reduced yields in low-fertility plots.

Developing Hybrids

Male steriles. Developing phenotypically and genotypically diverse, improved male steriles remains a high-priority objective. The process involves identifying good nonrestorer lines and converting them to male steriles. First back-crosses were made for 111 and second back-crosses for 74 nonrestorers while converting them to male steriles.

Some nonrestorers are now converted to male sterility and several were testcrossed on five selected restorer lines, A535, A701, CS-3541, D71396. and MR841. Resulting hybrids will be evaluated in the 1983 rainy season. B-lines of the most promising new male steriles (MB-2, MB-5, MB-6, MB-9, MB-10, and MB-12) were evaluated at ICRISAT Center, Dharwar, and Bhavanisagar. The trial included B-lines of commonly used Indian male steriles (2077B, 2219B, and BTx623 from Texas) for comparisons. The results indicated no significant differences from B-line controls for height or maturity but improved grain-mold resistance.

In the breeding program for the postrainy season, we hope to diversify seed parents for hybrids with better grain characters and resistance to leaf diseases. D84271A (from 2219A x CSV-5) is ready for testcross evaluation. And 14 F_4 lines from crosses to 2077A and 296A were test-crossed forming 453 hybrids, with 313 remaining male sterile. The pollen parents are now being backcrossed to develop A-lines.

Evaluating hybrids. Several hundred hybrids produced on 2219A, 2077A, and 296A were evaluated during the rainy season in nurseries or trials at ICRISAT Center, Dharwar, and Bhavanisagar. Approximately 20 new hybrids, superior in agronomic traits including yield potential, were selected for further testing in advanced hybrid adaptation trials in India or in International Hybrid Adaptation Trials in 1983.

Twenty-two hybrids initially selected for further testing in 1981 were evaluated for adaptation and yield stability at 1CRISAT Center, Dharwar, and Bhavanisagar (Table 22). 1CSH-110 was the most stable and productive with highest yields at all locations except Bhavanisagar. The evaluations were in Vertisol and Alfisol at ICRISAT Center under low- and high-fertility and sprayed and unsprayed environments.

Yields of most hybrids were reduced more than 50% by low-fertility, unsprayed conditions. Low fertility also delayed flowering of most hybrids about 1 week and reduced plant height about 25%. Head bug damage, being most severe on late-maturing hybrids, further reduced yields under low fertility.

We also evaluated 44 hybrids for yield during the rainy season at ICRISAT Center, and selected 3 on the existing A-line 2077 (2077A x D39599, 2077A x D39602, and 2077A x D39607); and 3 for advanced testing on new ICRISAT-developed A-lines (D1A x CS-3541, D2A x D71278-4, and D2A x D40957).

Results from other hybrids made on 2077A, 296A, D2A, and D3A led us to select 11 whose yields and lodging scores were better or much better than those of hybrid controls: (2077A x D37221, 2077A x D37215, 2077A x D37223,

Table 22. Mean grain yields (kg/ha) of some elite, advanced sorghum hybrids evaluated at three sites in India, rainy season 1982 (RCB, plot size variable: 4 m^2 minimum, 12 m^2 maximum).

Hybrids	Pedigree	Dharwar	Bhavani-sagar	ICRISAT Center HF[1] (2)[2]	ICRISAT Center LF[3] (4)[4]
ICSH-110	296Ax(SC108-3xCS3541)-51-l	6570	3850	7720	3910
ICSH-138	296Ax FLR-266xCSV-4-2-2-2-3-2	6410	2630	7720	3050
ICSH-136	296AxDiallel-475-746-4-5-2-1	5600	1710	6910	3560
ICSH-123	296Ax[(IS10927xUchV2)-16-lxCS-3541]-5	6410	4460	6770	3290
ICSH-137	296AxEarly Pop-5-1-1	6230	3920	6850	3180
ICSH-126	296Ax[(CS-3541 x ET2039)-1 1-1 x SC-108-3xl48]-29-3-l	6270	2100	7440	3010
ICSH-134	2219AxUchV2xG.G.x370-4-2-3	5650	2940	6260	3650
ICSH-122	296Ax SC108-3 x Swarna) x IS-9327 -6-1-2	6500	2870	6810	2930
ICSH-133	2219AxFLR-266xCSV-4-2-2-2-1-1	5330	2290	6600	3460
ICSH-121	2219Ax(SC-19803xCS-3541)-l-3-l	6120	2420	6240	3290
ICSV-107	(SC-108-3xCS-3541)-19-1 (SPV 351)	5920	2790	6280	2210
ICSV-108	(SC-108-4-8xCS-3541)-88 (SPV 386)	6540	3680	6280	1940
CSH-9	(Hybrid control)	6120	3870	5270	2420
SE		±322	±432		
CV (%)		10	25		

1. HF = High Fertility (128:82:0).
2. ICRISAT Center, two locations: Vertisol SE ± 389, CV(%) 10; Alfisol SE ± 509, CV(%) 14.
3. LF = Low Fertility (40:20:0).
4. ICRISAT Center, three locations: Alfisol SE ± 669, CV(%) 26; Alfisol (pesticide free) SE ± 407, CV(%) 35; Vertisol (pesticide free) SE ± 414. CV(%) 36.

This promising hybrid developed at ICRISAT Center, with high yields and a low rate of lodging, is especially suited to rainy-season cropping.

2077A x D37219, 2077a x D37209, 2077A x D37214, D2A x D37225, 296A x D37212, 296A x D37219, 296A x D37214, and D3A x D7I2784).

Evaluating hybrids on new A-lines. Our newly developed A-lines were crossed with selected restorers to produce 145 hybrids that were evaluated in 1982 at ICRISAT Center. Dharwar, and Bhavanisagar. Nine hybrids whose grain yields were as good or better than those of control hybrids are: MA-2 x MR-836, MA-2 x M R-877, MA-3 x MR-830, MA-5 x MR-836, MA-5 x MR-852, MA-5 x MR-890, MA-6 x MR-850, MA-5 x MR-802,and MA-10 x MR-861. Those nine new hybrids resist lodging and leaf diseases and are less susceptible to grain molds than existing commercial hybrids included in the trial.

Cooperative Multilocational Testing

Our cooperative activities with national programs primarily involves evaluating our International Sorghum Variety Adaptation Trial (ISVAT), International Sorghum Hybrid Adaptation Trial (ISHAT) and distributing improved breeding lines. All those activities were extended to more SAT countries. Data from 1981 International Sorghum Preliminary Yield Trials, ISPYT-1 and ISPYT-2, and the Sorghum Elite Progeny Observation Nursery (SEPON) were received too late in 1982 to be analyzed for the 1981 Annual Report. They are reported here.

International Sorghum Variety Adaptation Trial (ISVAT)

This trial merged previous international trials ISPYT-1, ISPYT-2, and SEPON. Thus ISVAT is composed of the best varieties, plus other varieties identified and selected for superior performance, adaptation, and agronomic eliteness in our other breeding projects.

ISVAT consisted of 23 varieties and a local control contributed by our cooperators. The trial went to 47 locations in 36 countries. Data are now arriving but most of the data will be received during 1983.

International Sorghum Hybrid Adaptation Trial (ISHAT)

This trial consisted of 23 hybrids and a local control hybrid contributed by our cooperators. It went to 30 locations in 24 countries. We expect to receive data from most locations by mid-1983.

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

The 1981 ISPYT-1 consisted of 24 early- to medium-maturity varieties derived from improved populations including CSH-6, a hybrid check (control), and a local control contributed by cooperators. The trial went to 37 locations in 18 countries, data received from 16 locations in 7 countries show several varieties performing well at various locations (Table 23).

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

The 1981 ISPYT-2 consisted of 24 medium-maturing varieties, 2 hybrid controls, and a local variety contributed by cooperators. The trial went to 37 locations in 18 countries; data have been received from 16 locations in 7 countries (Table 24).

Sorghum Elite Progeny Observation Nursery (SEPON)

SEPON-1981 consisted of48 entries, including a hybrid control (CSH-6) and a local control contributed by cooperators. The test material was mostly in advanced generations (F_6 and more) of medium maturity and height. A few entries that performed well in 1980 SEPON were included. The nursery went to about 50 cooperators in the semi-arid tropics. SEPON-1981 performance data were received from 20 locations outside India. Average grain yields of the entries ranged from 1785 to 3488 kg/ha. Average performances of 15 selected entries from SEPON 1981 are presented in Table 25; (E35-1 x TAM-428)-4-3 and SPV-387 were least affected by molds.

Contribution to National Programs

E35-1 has moved increasingly in Upper Volta to more productive fields close to farmers' dwellings. Another variety, M60256 (SPV-386), was provisionally released in Zambia with 1600 kg of seed for 1982.

Four varieties from the ICRISAT population breeding program went on the market in China after 2 years of local selection and evaluation. They are named Yuan 1-54 (A6072), Yuan 1-98 (A3681), Yuan 1-28 (A3872), and Yuan 1-505 (A3895).

Two ICRISAT varieties (CENTA SS-41 and San Miguel No.1), selected from SEPON, were released in E1 Salvador.

In India M60252 (SPV-351) was included in minikit testing, and we expect M60256 (SPV-386) will enter minikit in 1983. Seed of three varieties, M35544, SEPON-77 (PR-79-99-100), and M60251, were increased in 1982 to 1 tonne of each used for wide-scale testing in Venezuela.

Varieties resistant to midge being used in India and Argentina include PM1052, PM1060, PM1059, PM1063-2, PM1064, PM1065, PM1069, PM1070, PM1076, PM1079, PM39656, PM39658, PM39704, PM39792, and PM39833. Seed oftwo Striga-resistant varieties,

Table 23. Grain yields (kg/ha) of indicated entries in the International Sorghum Preliminary Yield Trial-1, 1981.

Origin	Pedigree	Indian sub-continent [a]	Niger Ole. Kolo	Zimbabwe, Nyanda Province	Malawi, Ngabu	Thailand [b]	Taiwan, Chiayi	Overall Mean
A6252	(E35-1xUs/B-487)-2-1-4-1-2	3480 [c]	1730	2160	4750	3010	6550	3500
A7001	(E35-1xUs/B-287)-2-1-2	3530	2710	4260	3580	2670	6250	3590
A6149	(E35-1xRs/B-342)-2-2-3-1	3640	2780	2500	3090	2670	6250	3520
A6259	(E35-1xRs/B-394)-1-1-2	3700	2710	3530	3390	3690	6250	3770
A6299	[(CSV-4x(G.G.x370)]-4-4-2	3770	2360	4950	4010	3370	7300	3940
A6306	[(CSV-4x(G.G.x370)]-2-1-4-4	3430	2370	5070	3390	3230	9320	3810
A6201	Indian Synthetic-323-1-3	3680	3610	3640	3700	2350	3220	3480
A6092	Indian Synthetic (Tall)-387-3-3	3960	2500	3420	3390	1960	5300	3630
A6103	Indian Synthetic-600-3-3	3620	3190	4460	3700	1850	6150	3590
	CSH-6	4090(1)	2850	4430	2900	2660	5850	3890
	Local [c]		2260	3710	3150	2740	3520	-
	SE [d]		±315	±189	±278		±370	
	CV % [e]		27	23	18		13	

a. Includes 9 locations in India and 1 in Pakistan (Safiwal).

b. Mean of 2 locations from Thailand (Khon Kaen and Tak-Fa).

c. Local controls variable.

d. SE of mean grain yield (kg/ha) of the Indian subcontinent locations ranged from ±101 to ±547, and of Thailand locations was ±182 and ±87.

e. CV (%) of the Indian subcontinent locations ranged from 8 to 48, and of Thailand locations was 9 and 11.

An elite sorghum variety SPV 351, developed by 1CR1SA T. has proved superior in tests on farms in India, and is within one step of release to farmers.

SAR-1 and SAR-2, have been increased for extensive farmers' field testing in parts of Maharashtra, India.

Varietal, hybrid, and some sources of resistance have moved up through national testing systems and, in several instances, have been released to farmers.

Looking Ahead

Insects. Shoot fly work will concentrate on identified resistance sources to study their behavior under no-choice conditions and to group them by their resistance mechanisms.

Top priority for sorghum midge will be classifying breeding material for resistance under head cages.

We shall improve the artificial-infestation method of verifying resistance in lines identified for stem-borer resistance under natural conditions.

The screening procedure for headbugs will be improved and more information collected on their biology and ecology.

Diseases. Several grain mold-resistant, colored-grain sorghum cultivars recently identified will be used in the breeding program. Inheritance of grain-mold resistance in colored-grain types will be determined, and studies to understand relationships among seed color, high tannin, and grain-mold resistance will be continued and intensified.

Striga. Breeding efforts will be intensified to strengthen *Striga* resistance in identified sources and breeding lines. Grain and food quality of the Striga-resistant lines will be improved. Techniques to screen individual plants for *Striga* resistance will be refined.

Physical environment. We will continue to try to improve techniques for screening lines for

Table 24. Grain yields (kg/ha) of selected entries in the International Sorghum Preliminary Yield Trial-2, 1981.

Origin	Pedigree	Indian sub-continent [a]	Niger Ole. Kolo	Zimbabwe, Nyanda Province	Malawi Ngabu	Thailand [b]	Taiwan Chiayi	Overall Mean
A6106	(E35-1xUs/R-408)-8-2	3470	1730	1020	3330	2540	7050	3310
A3666	(E35-1xRs/B-253)-2-1-1-1	3350	4280	1460	2590	2760	5620	3310
A6142	(E35-1xFLB-182)-2-1-3-1	3180	3460	820	3460	2930	5350	3180
A6178	(UchV$_2$xFLR-101)-3-3	2840	1890	2070	3390	2920	6870	3030
A6298	[CSV-4x(GGx370)]-2-2-2	3500	2850	1950	2840	2730	7350	3470
A3263	[CSV-4x(RsxVGC)]-1-1-1	2690	2410	1310	4440	3600	4750	2940
A6351	(Rs/RxCSV-4-1525)-1-1-4	2940	3140	1970	3580	3260	5350	3120
A6149	(E35-1xRs/B-342)-2-2-3-1	3740	2800	1040	2840	2580	6200	3470
	CSH-6	3970	3120	3780	3270	2820	4650	3760
	CSH-5	3920	3200	2780	4640	3120	6750	3920
	Local [c]	3330	2200	1640	3700	3480	3120	
	SE [d]		±543	±124	±334		±357	
	CV % [e]		44	37	19		13	

a. Mean yield includes 8 locations in India and 2 in Pakistan (Dadu & Safiwal).

b. Mean yield of 2 locations from Thailand (Khon Kaen and Bangkhen).

c. Local control variable.

d. SE of Indian subcontinent locations ranged from ±44 to ±653, and of Thailand locations was ±100 and ±357.

e. CV (%) of Indian subcontinent locations ranged from 6 to 38, and of Thailand locations was 14 and 17.

Table 25. Performance of indicated varieties from Sorghum Elite Progeny Observation Nursery (SEPON), 1981.

Origin	Pedigree	Grain yield (kg/ha) America (2)[a]	Africa (10)	Asia (2)	India (4)	Mean
M36136	(IS 12611xSC 108-3)-1-2-1 (SPV 391)	2320	2850	4420	4270	3230
M36170	(E35-1 x TAM-428)-4-3	2310	2410	3820	2770	2640
M36056	[(SC 423xCS 3541)xE35-1] -2-1 (SPV 387)	3450	2630	3550	4650	3310
M36229	[(SC 108-3xSwarna)xE35-1]-6-2	3890	2780	3440	4770	3420
M39335	[(IS 12622Cx555) (3612Cx2219B) -5-1)xE35-1]-5-2(SPV 475)	2430	2500	2240	4410	2890
M36007	(SC 108-3xCS 3541)-19-1 (SPV 351)	2290	2250	3080	4830	2920
M36095	(IS 12611 xSC 108-3)-1-1-2-1 (SPV 471)	1630	3220	3320	4250	3230
M36178	t(148xE35-1)-4-1xCS3541 deriv.]-5-3-6 (SPV549)	2540	2800	3140	3820	3030
M36200	[(148 x E35-1)-4-1 xCS 3541 deriv.] -5-4-2-1	1810	2970	2990	4500	3180
M36197	[(148xE35-1)-4-1xCS3541deriv.] -2-3-1	1650	3260	3930	4680	3490
M36528	[(SC 423 x CS 3541) x E35-1]-9-1	2370	3050	3600	4200	3310
M36435	[(SC 108-3xSwarna)xCS 3541) -7xGroup 1II]-1	3000	2860	4020	3630	3170
M39281	(SC 108-4-8xCS 3541)-88 (SPV 386)	3230	2850	4070	4920	3490
M36168	(SC 108-4-8xCS 3541)-4-2-1	3580	2720	3800	5000	3480
M36121	[(SPV 35xE35-1)xCS 3541] -8-1 (SPV 472)	1540	2850	2990	4000	2980
	Coordinated Sorghum Hybrid-6 (CSH-6)	3190	2300	1990	3850	2670
	Local	1230	2310	6370[b]	2980	2600

a. Numbers in parentheses are number of locations involved. Local varieties varied and could be a local variety or improved variety.
b. Grain yield data from only one location.

improved crop establishment and drought resistance. We will systematically screen the germplasm and breeders' lines for morphological and physiological traits associated with drought resistance and crop establishment, two major problems. As we describe material, we will make it available to breeders and physiologists for their national breeding programs or for basic physiological studies in universities and research institutes outside ICRISAT.

The lattice design is efficient in drought situations, but we hope to modify field designs to improve evaluation efficiency.

Selection, alternating between optimal and stress situations, will continue.

Nitrogen fixation. The possibility of using the N isotope-dilution technique in pot culture to screen sorghum lines for ability to stimulate N-fixation will be explored.

We will screen sorghum lines for stimulation of nitrogenase activity in tube culture and in pots, using both the acetylene reduction assay and the effect of inorganic combined nitrogen on activity.

By field trials, we will continue to examine the response by sorghum to inoculation with different nitrogen-fixing bacteria, and to examine long-term nitrogen balance.

We will use the synthetic exudate medium and the aseptic plant culture system to screen our large collection of N-fixing bacterial isolates for potential inoculants. We also will study competition and synergistic effects on plant growth and N-fixation of mixed bacterial cultures used as inoculants.

We hope to develop a system of seedling-plant culture that enriches the bacteria type(s) preferentially residing in the rhizosphere of a cultivar. We will isolate and screen vesicular arbuscular mycorrhizal (VAM) fungi from India's traditional sorghum-growing areas, and survey genotypic variation in root colonization of sorghum by VAM in the field. Pot trials will be conducted to determine effects of type and level of P fertilizer and response to inoculation with VAM.

Food quality. Basic information available on sorghum food quality, particularly endosperm texture, will be used to identify routine methods to evaluate grain samples without cooking. Efforts to improve food quality of the rainy season crop will be intensified by screening for reduced sprout damage, alpha-amylase activity, pigmentation, and weathering. A second set of International Sorghum Food Quality Experiments will be initiated.

Population improvement. Recurrent selection will be continued on the six populations we are improving. Improved populations in advanced cycles will be evaluated in West, East, and southern Africa to determine and select appropriate populations best suited to those geographical areas. We hope to initiate a population for the postrainy season.

Developing hybrids. Emphasis will continue on developing improved new male steriles for both rainy and postrainy seasons, and these will be evaluated in hybrid combinations from selected pollinators.

Postrainy season adaptation. Effects of continued selection at and between locations will be evaluated, and how sowing date affects crop performance will be further evaluated, as will photoperiod-sensitivity in relation to late sowing.

To develop further broad-based material for screening, we shall use germplasm lines from drier parts of Africa in the postrainy-season program. And we will continue to evaluate hybrids for the postrainy season.

Publications

Journal Articles

MAITI, R.K., RAJU, P.S., and BID1NGER, F.R. 1981. Evaluation of visual scoring for seedling vigour in sorghum. Seed Science and Technology 9:622.

MURTY, D.S., NICHODEMUS. K.D., and HOUSE, L.R. 1982. Inheritance of b*asmati and* dimpled seed sorghum. Crop Science 22(5): 1080-1082.

MURTY, D.S., PATIL. H.D., PRASADA RAO, K.E., and HOUSE. L.R. 1982. A note on screening the Indian sorghum collection for popping quality. Journal of Food Science and Technology 19(2): 79-80.

WILLIAMS, R.J.,DANGE,S.R.S., MUGHOGHO, L.K., and RAO, K.N. 1982. Identification of QL-3 sorghum, a source of resistance to *Peronosclerospora sorghi.* Plant Disease 66:807-809.

WILSON, G.L., RAJU, PS., and PEACOCK, J.M. 1982. Effect of soil temperature on seedling emergence in sorghum. Indian Journal of Agricultural Sciences 52:848-851.

Conference Papers

AGARWAL, B.L.,and HOUSE, L.R. 1982. Breeding for pest resistance in sorghum. Pages 435-446 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India; ICRISAT.

ALAGARSWAMY, G., and SEETHARAMA, N. 1982. Nitrogen uptake and translocation to the grain in sorghum. Pages 337-340 *in* Genetic Specificity of Mineral Nutrition of Plants (ed. M.R. Sariac). Serbian Academy of Science and Arts, Beograd.

BHOLA NATH. 1982. Population breeding techniques in sorghum. Pages 421-434 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

HOUSE. L.R., and VASUDEVA RAO, M.J. 1982. *Striga*—problems and prospects. Paper presented at the ICR1SAT-ICAR Working Group Meeting on *Striga* Control, 30 Sept - 1 Oct 1982, ICRISAT, Patancheru, A.P., India.

MUGHOGHO, L.K. 1982. Strategies for sorghum disease control. Pages 273-282 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

MURTY, D.S., Patil, H.D.. and House, L.R. 1982. Studies on processing and cooking characters in sorghum. Paper presented at the All India Coordinated Sorghum Improvement Project Workshop, 17-19 May 1982. Pune, India.

MURTY. D.S., PATIL, H.D., and HOUSE, L.R. 1982. *Sankati* quality evaluation of sorghum cultivars. Pages 36-38 *in* Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

MURTY, D.S., PATIL, H.D., and HOUSE, L.R. 1982. Sorghum *Roti:* II. Genotypic and environmental variation for *roti* quality parameters. Pages 79-91 *in* Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

MURTY, D.S., PATIL, H.D., and HOUSE, L.R. 1982. Cultivar differences for gel consistency in sorghum. Pages 289-293 *in* International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

MURTY, D.S., and SUBRAMANIAN, V. 1982. Sorghum *Roti:* I. Traditional methods of consumption and standard procedures for evaluation. Pages 73-78 in Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

PEACOCK, J.M. 1982. Response and tolerance of sorghum to temperature stress. Pages 143-160 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

PRASADA RAO, K.E., and MURTY, D.S. 1982. Sorghum for special uses. Pages 121-128 *in* Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

ROONEY, L.W., and MURTY, D.S. 1982. Evaluation of sorghum food quality. Pages 571-588 *in* Sorghum in the Eighties: Proceedings of the Interantional Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

ROONEY, L.W., and MURTY, D.S. 1982. Color of sorghum food products. Pages 323-329 *in* Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

SEETHARAMA, N., SIVAKUMAR, M.V.K., BIDINGER, F.R., SARDAR SINGH, MAIT1, R.K., REDDY, B.V.S., PEACOCK, J.M., REDDY, S.J., MAHALAKSHMI, V., SACHAN, R.C., SHIV RAJ, A., MURTHY, S.R.K., NARAYANAN, A., TISSA KANANGARA, DURLEY, R.C., and SIMPSON, G.M. 1981. Problems and prospects for increasing yield under drought: criticism and synthesis with sorghum. Paper presented at the IARI Workshop on Plant Physiology and Biochemistry in the Eighties, 23-25 Nov 1981, New Delhi, India.

SEETHARAMA, N., WADE, L.J., PEACOCK, J.M., VERMA, P.K., REGO, T.J., and SARDAR SINGH. 1982. Effect of nitrogen and water stress on leaf-area development in sorghum. Pages 595-600 *in* Plant Nutrition 1982, Proceedings of the Ninth International Plant Nutrition Colloquium (ed. A. Scaife), Commonwealth Agricultural Bureaux, Slough SL2 3BN, UK.

SUBRAMANIAN, V., MURTY, D.S., JAMBUNATHAN, R., and HOUSE, L.R. 1982. Boiled sorghum characteristics and their relationship to starch properties. Pages 103-109 *in* Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

VASUDEVA RAO, M.J., CHIDLEY, V.L., and HOUSE, L.R. 1982. A three-stage screening methodology for Striga-resistance screening in the field.

Paper presented at the All India Coordinated Sorghum Improvement Project Workshop, 17-19 May 1982, Pune, India.

VASUDEVA RAO, M.J., CH1DLEY, V.L., and HOUSE, L.R. 1982. Genetic control of *Striga asiatica* in sorghum. Paper presented at the ICRISAT-ICAR Working Group Meeting on *Striga* Control, 30 Sept-1 Oct 1982, ICRISAT, Patancheru, A.P., India.

VASUDEVA RAO, M.J., RAGHAVENDER, B., CHIDLEY, V.L., and HOUSE, L.R. 1982. Methodology for *Striga* research. Paper presented at the ICRISAT-ICAR Working Group Meeting on *Striga* Control, 30 Sept-1 Oct 1982, ICRISAT, Patancheru, A.P., India.

Miscellaneous

SHARMA, H.C., and DAVIES, J.C. 1982. The oriental armyworm, *Mythimna separata* Walker—distribution, biology, and control; a literature review. Miscellaneous Report No. 59. London, UK: Centre for Overseas Pest Research.

PEARL MILLET

Contents

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PEARL MILLET

Physical Stresses

Drought Resistance

A procedure for analyzing the relative effects of (1) yield potential, (2) drought escape (time of flowering), and (3) drought resistance/susceptibility on cultivar yields in drought resistance tests was reported previously(ICRISAT Annual Report 1978/79). The procedure indicated that 40 to 60% of the variation in grain yields under stress could be explained by variation in yield potential and drought escape, and that those effects must be removed before an accurate estimate of varietal drought resistance or susceptibility can be made.

The procedure for calculating drought response of a cultivar has been slightly modified since the 1978/79 report. Cultivars with actual grain yields that are within one standard deviation of the yield predicted from yield potential and time-of-flowering data are considered to have drought indices of zero, as such a difference is within expected or normal variation. Entries whose measured yields differ from the predicted yields more than one standard deviation are assigned an index that reflects the difference in multiples of the standard error. Drought index values by this system typically range from -2 to +2, with zero for most lines in a given test; that is, their yields do not differ from their expected yields for their particular yield potential and time of flowering.

Drought-resistance screening experiments between 1977 and 1979 included established cultivars, breeding lines, and source materials that differed considerably in yield potential. As a result, a significant portion of the variation in yields under midseason or terminal stress simply reflected variation in yield potential (Table 1). Since 1981, however, we have concentrated on screening only advanced breeding lines that differ little in yield potential, so drought escape and drought resistance/susceptibility are the major factors influencing grain yields in a drought situation. Now we can focus on those two factors in analyzing cultivar performance and establish how each factor affects components of grain yield—to help us answer, is drought escape or resistance expressed through more heads per plant, more grains per head, or otherwise?

Since the drought index measures relative performance (actual to expected), the relative expression of the various yield components (stress to control) was correlated to the calculated drought index and to time of flowering. For the terminal (which begins with flowering of the main shoot) stress treatment, the expression of both drought escape (Table 2) and drought response (Table 3) was consistent both years. Drought escape correlated significantly with relative yield through relative grain numbers per head and individual grain weight. In all cases,

Table 1. Average percentage of variation in measured grain yields of pearl millet attributable to variation in yield potential, time of flowering, and drought response index for variety and source material tests (1977-1979) and for advanced breeding products tests (1981/1982), ICRISAT Center.

	Percentage of variation explained	
	1977-1979	1981/1982
Mid-season stress		
Yield potential	44	1
Time of flowering	8	44
Drought index	41	43
Terminal stress		
Yield potential	20	1
Time of flowering	32	53
Drought index	41	38

Table 2. Correlations between drought escape (days to flowering) and relative yield components (stress as a proportion of control) in pearl millet in advanced screening under terminal drought stress, 72 entries each year in 1981 and 1982, ICRISAT Center.

	1981	1982
Grain yield	-.70**	-.49**
Plants/m^2	.15	-.25*
Heads/ plant	-.09	-.03
Grains/ head	-.66**	-.40**
Weight/grain	-.42**	-.38**

correlations were negative as expected; that is, earlier flowering lines had higher relative yields, grain numbers per head, etc., than later flowering lines. Relative numbers of heads per plant were not related to drought escape in either year; productive plant numbers were related one year but not the other.

Drought index was similarly related to relative grain number per head and individual grain size both years. The relationships were positive, indicating that lines rated drought resistant could maintain grain number per head and grain size under stress better than lines rated drought susceptible. Maintaining head numbers per plant (and productive plant numbers) was not related to drought resistance.

Relationships with grain number per head and grain weight were expected under drought stress, because those two yield components are most affected by a stress during grain filling. That the drought index correlated positively with those two components of yield after effects of drought escape were removed is encouraging evidence that variability in response to stress does not depend only on drought escape.

Table 3. Correlations between drought index and relative yield components (stress as proportion of control) in pearl millet in advanced screening under terminal drought stress, 72 entries each year in 1981 and 1982, ICRISAT Center.

	1981	1982
Grain yield	.55**	.61**
Plants/m^2	-.07	.15
Heads/plant	.14	.14
Grain/head	.34**	.41**
Weight/grain	.38**	.38**

Correlations of both drought escape and drought index with relative yield components in midseason stress were not consistent the 2 years. In 1981 only heads per plant correlated with the drought index, but in 1982 productive plant numbers and grain per head correlated with the drought index. Whether the variation reflects differences in stresses or in the material is not known.

Such analyses, over time, should help us understand how yield is determined under stress and how resistance to stress is expressed by specific components of grain yield.

Crop Establishment

Studies in Aurepalle village (ICRISAT Annual Report 1981) suggested that plant populations in farmers' fields were generally lower than the All India Coordinated Research Project for Dryland Agriculture recommends—and that variation of space between plants was often large with gaps in the crop and places where plants were too closely 'clumped' together. Observations in farmers' fields in other millet-growing areas in India suggest that wide between-plant variation is common (Fig. 1).

How much uneven plant stands affect millet grain yields is not known, though a tillering crop like millet has considerable ability to compensate for gaps in plant stand. But the ability to compensate will depend on the degree of variation in the stand, plant population, and a range of environmental conditions.

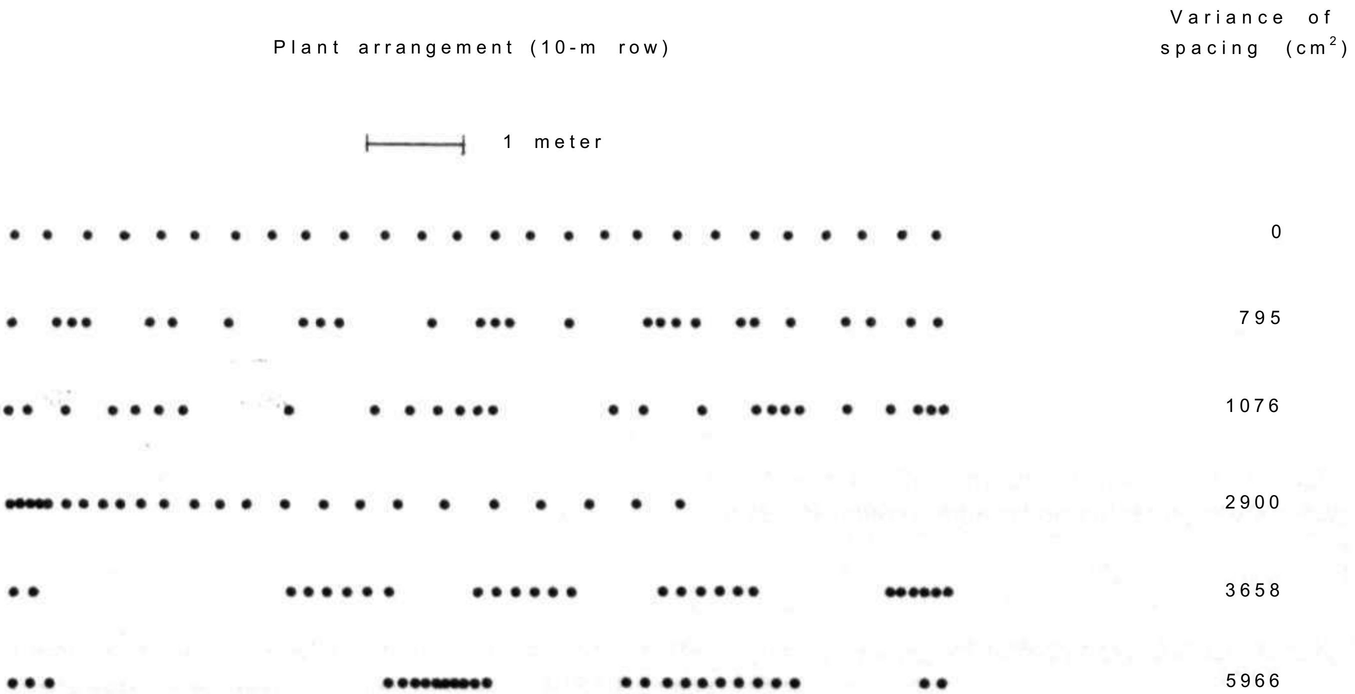
We initiated a research project in 1981 to quantify some of these effects, and to better define an adequate plant stand for pearl millet. We designed a series of 20 within-row plant arrangements so variance in the average spacing between plants ranged from zero (identical spacing between all plants) to approximately 10 000

cm^2 (Fig.1). Each row was bordered on both sides by a row of evenly spaced plants to minimize between-row effects.

Variance treatments were used in a replicated experiment in 1981 with two plant populations (50 000 and 100 000 plants/ha) and in 1982 with the same plant populations and two fertility levels (0 and 100 kg N/ha). Grain yields from each of the 10-m row lengths were plotted against the spacing variance for that row, and the relationship of yield and variance in plant spacing was determined for years, populations, and fertility level.

Yields in 1981 were high for both the high and low population plantings with regular plant spacing in the row (low variance). Under those conditions increase in spacing variance reduced yields markedly, particularly over the lower end of the range of variance (Fig.2). Increasing variance from zero to 1000 reduced yields 40% in high populations and 31 % in the low plant populations. The apparently greater decline in yield in the high population may have resulted from

Figure 1. Variation in plant-to-plant spacing in a farmer's millet field is seen above. To find out how these spacings affect yields, ICRISAT scientists devised a method with between-row spacing and plant populations constant and variance of plant-to-plant spacing from 0 to 10000 cm^2. A sample plant arrangement scheme is shown below with dots.



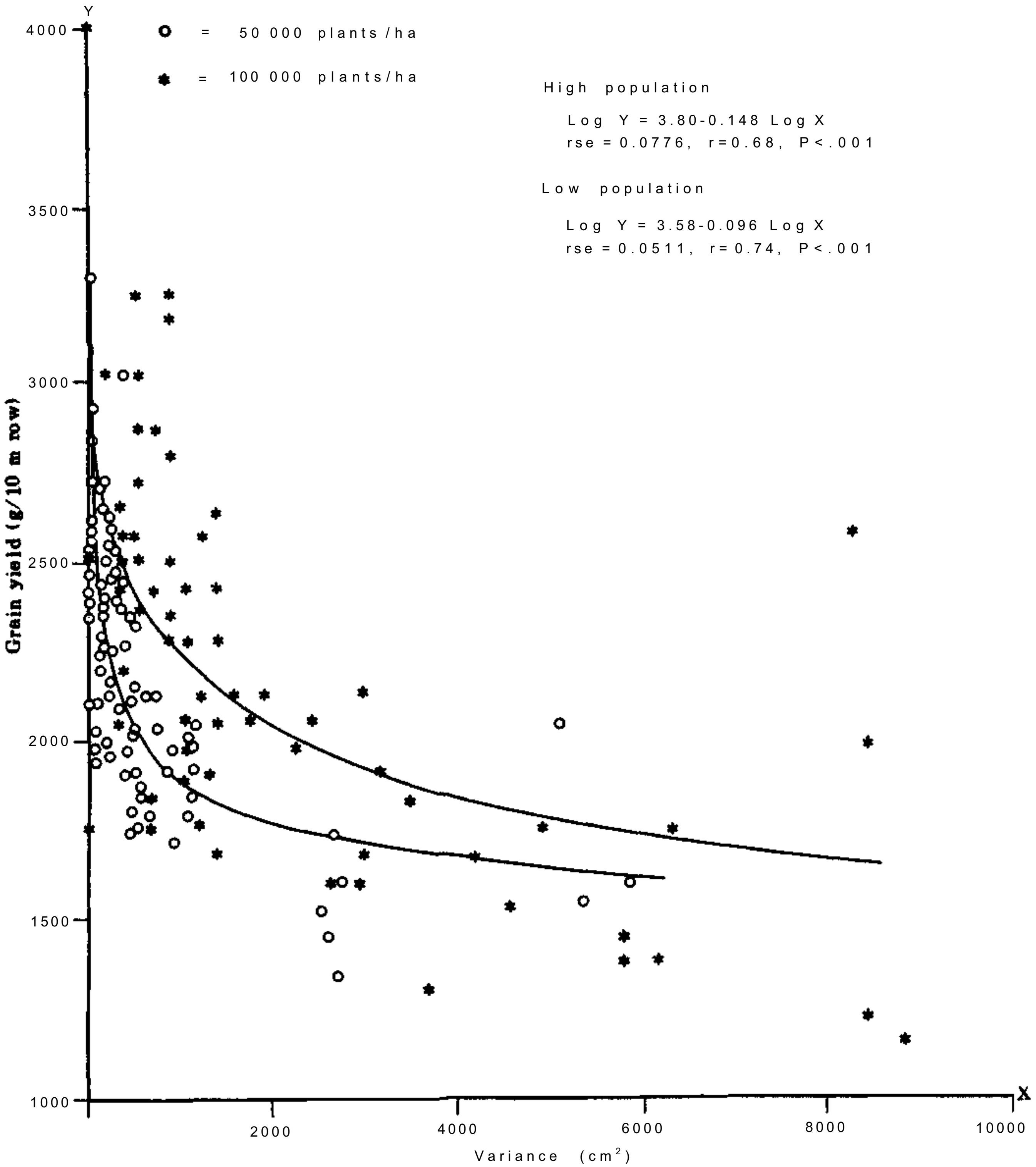


Figure 2. Grain yield as a function of variance of plant-to-plant spacing for plant populations of 50000 plants/ha and 100 000 plants/ha under high fertility, ICRISAT Center, 1981.

more clumping of plants in the higher population than in the lower population for a given variance.

Yields were poorer and varied more in 1982, but spacing variance effects were similar to those in 1981, particularly for the low-population, low-fertility crop, an approximation of farmers' fields (Fig.3). Yields under low fertility decreased an average 33% when variance changed from zero to 1000; under higher fertility the decline was 10%.

Variances in plant spacing in 75% of the farmers' fields in Aurepalle village ranged from 1000 to 2500 cm^2, which corresponds closely to

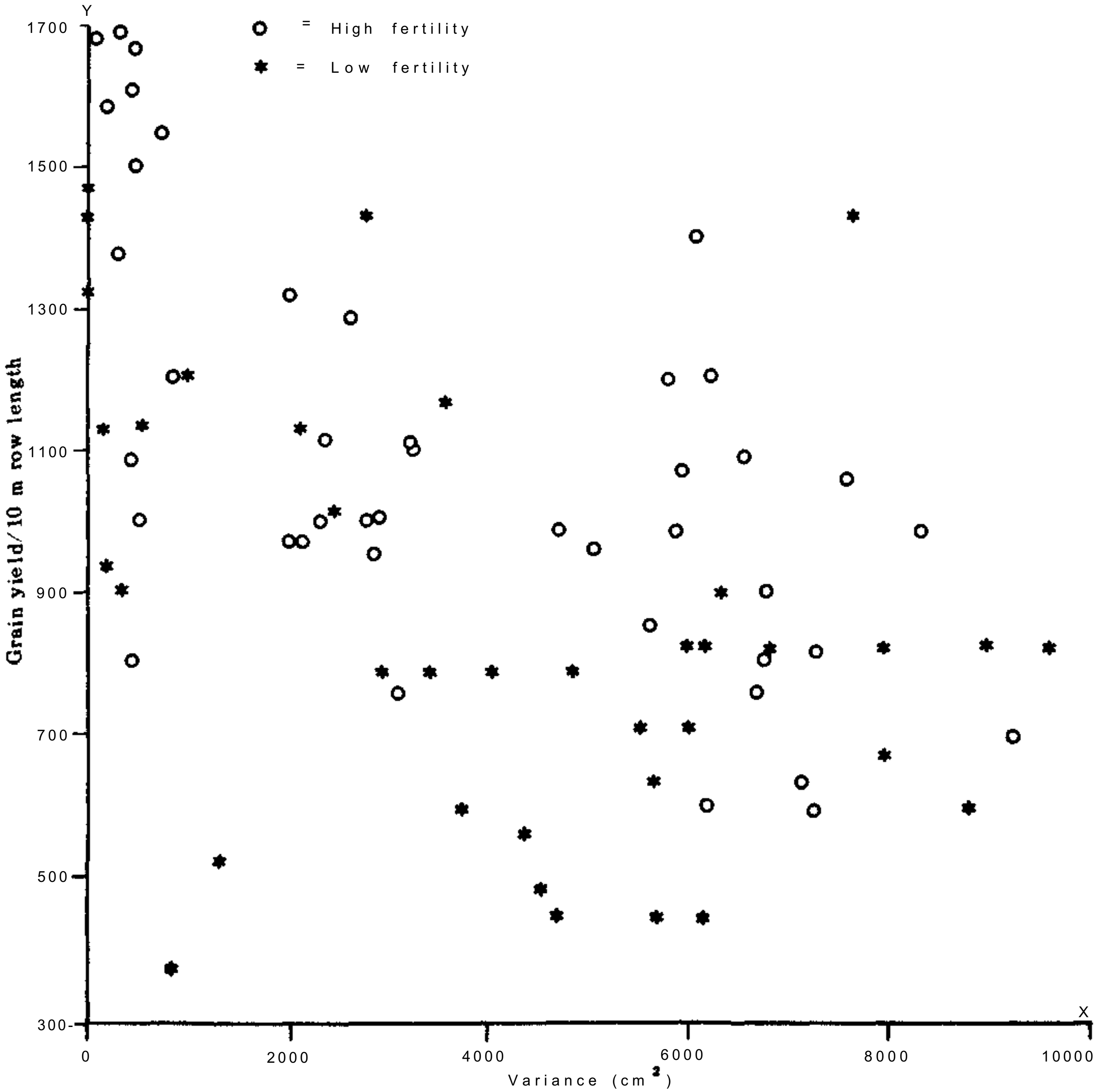


Figure 3. Grain yield as a function of variance of plant-to-plant spacing of high-fertility and low-fertility treatments, 50000 plants/ha population, ICRISAT Center, 1982.

the range for most of the yield decline both years and at both yield levels. Other management factors probably were better in our experiments than in farmers' fields, so spacing variance may have reduced yields more for us than for farmers. Still the data suggest that farmers are losing yield by uneven between-plant spacing. The 1981 data suggest that spacing may influence yields more than plant populations do.

Biotic Stresses

Biology and Epidemiology

Downy Mildew (*Sclerospora graminicola*)

Detecting pathogenicity differences. In the University of Reading/ODA/ ICRISAT Project on variability in the downy mildew (DM) pathogen, distinct differences in pathogenicity between West African and Indian populations of *Sclerospora graminicola* were detected. Pearl millet hybrids MBH 110 and ICH 105 were highly resistant to Indian inoculum but moderately susceptible to the West African samples. When the pathogen samples were tested over a range of host cultivars, West African samples were generally more pathogenic, and caused higher DM incidence than samples from India. Samples within West Africa also differed—those from Nigeria, Upper Volta, and Niger were most pathogenic, those from Senegal intermediate, and those from the rest of West Africa and India least pathogenic.

Those results broadly confirm results from several years of IPMDMN testing, and show that variation is primarily genetic rather than conditioned by environmental differences between and within continents. Still environment may influence expression of some resistance genes. We intend to characterize the pathogen populations further to establish whether resistance is usually under single gene or polygenic control.

Detecting pathogenicity differences between isolates. In an attempt to detect variability in the population of *S. graminicola* in India, we compared the pathogenicity of oospores collected during 1981 rainy season at Durgapura Research Station (Jaipur, India) with ICRISAT Center oospores, and planted surface sterilized seeds of NHB 3 and 7042 in sterilized oospore-inoculated soil in pots. Both cultivars were tested with each isolate. In two tests, no DM was detected on NHB 3 with Durgapura oospores, while 7042 developed 54% DM, and both the cultivars were highly susceptible, as expected, to ICRISAT Center oospores. Results from sporangial-infection tests were similar to oospore infection except that 14% of NHB 3 developed DM from sporangia of the Durgapura isolate. Possibly the virulence of the pathogen has shifted at Durgapura in the absence of this particular host genotype whose cultivation was abandoned several years ago.

Stunt reaction. In laboratory, glasshouse, and field studies at ICRISAT Center, BJ 104 and its female parent, 5141 A, developed a characteristic stunted appearance after inoculation with 5. *graminicola.* Stunted plants generally remain less than 10 cm tall, have mottled leaves, and produce little or no asexual sporulation. The stunt reaction is independent of seedling stage at inoculation, inoculum concentration, and pathogen isolate.

To study the significance of the stunt reaction during the 1982 rainy season, we planted two isolation plots (each 400 m^2) of BJ 104 surrounded by a 1-m wide band of heavily DM-infected 7042 (as a source of inoculum) and two similar plots were planted without a source of inoculum and at least 500 m from each other or from another pearl millet field.

DM incidence taken 23 and 39 days after planting showed that two plots with the inoculum source developed 44% and 15% DM with three reaction types: (1) plant severely stunted with virus-like yellow mottling, (2) plants slightly to moderately stunted with virus-like yellow mottling, and (3) plants with normal DM symptoms. Percentages of three reaction types were 43, 55, and 2, respectively, in the first inoculated plot and 45, 54, and 1, respectively, in the second inoculated plot. Stunted plants produced no oospores. No DM was detected in plots without an inoculum source.

Since stunted plants support little or no asexual sporulation, BJ 104 is likely to be resistant in situations where developing an epidemic depends mainly on the supply of inoculum from within the crop (esodemic). Under exodemic conditions, however, DM can be very high in BJ 104.

Ergot (*Claviceps fusiformis*)

Alternative host. In view of recent reports that *Cenchrus ciliaris* from Durgapura, Rajasthan (G. Singh, personal communication), and *Panicum antidotale,* from Hissar, Haryana,(Thakur, D.P. and Z.S. Kanwar, 1978. Indian J. Agric. Sci. 48:540-542.) are alternative hosts of the pearl millet ergot pathogen, *Claviceps fusiformis,* we inoculated eight grass species with the ICRISAT Center ergot isolate during the 1982 rainy season. A minimum of 10 inflorescences were inoculated in each of *Cenchrus ciliaris, Panicum antidotale, Panicum maximum, Paspalum notatum, Pennisetum massaicum, Pennisetum squamulatum, Pennisetum ruppelli,* and *Setaria sphacelata,* and *Pennisetum americanum* as the check. None other than *Cenchrus ciliaris* and *Pennisetum americanum* showed any ergot symptoms. In a later screenhouse experiment, *Cenchrus ciliaris's* susceptibility to the pearl millet ergot and vice versa were confirmed by cross-inoculation tests.

It seems that in Rajasthan, India's major pearl millet growing state, *Cenchrus ciliaris,* a widespread grass species, is a major source of ergot inoculum. This grass may, however, affect the ecosystem favorably for millet plants (see the mycorrhiza section of this report).

Smut (*Tolyposporium penicillariae*)

Biology. Sporeballs of *T. penicillariae* varied from circular to near polyhedral and measured 42 to 325 x 50 to 175μ. The number of telios-

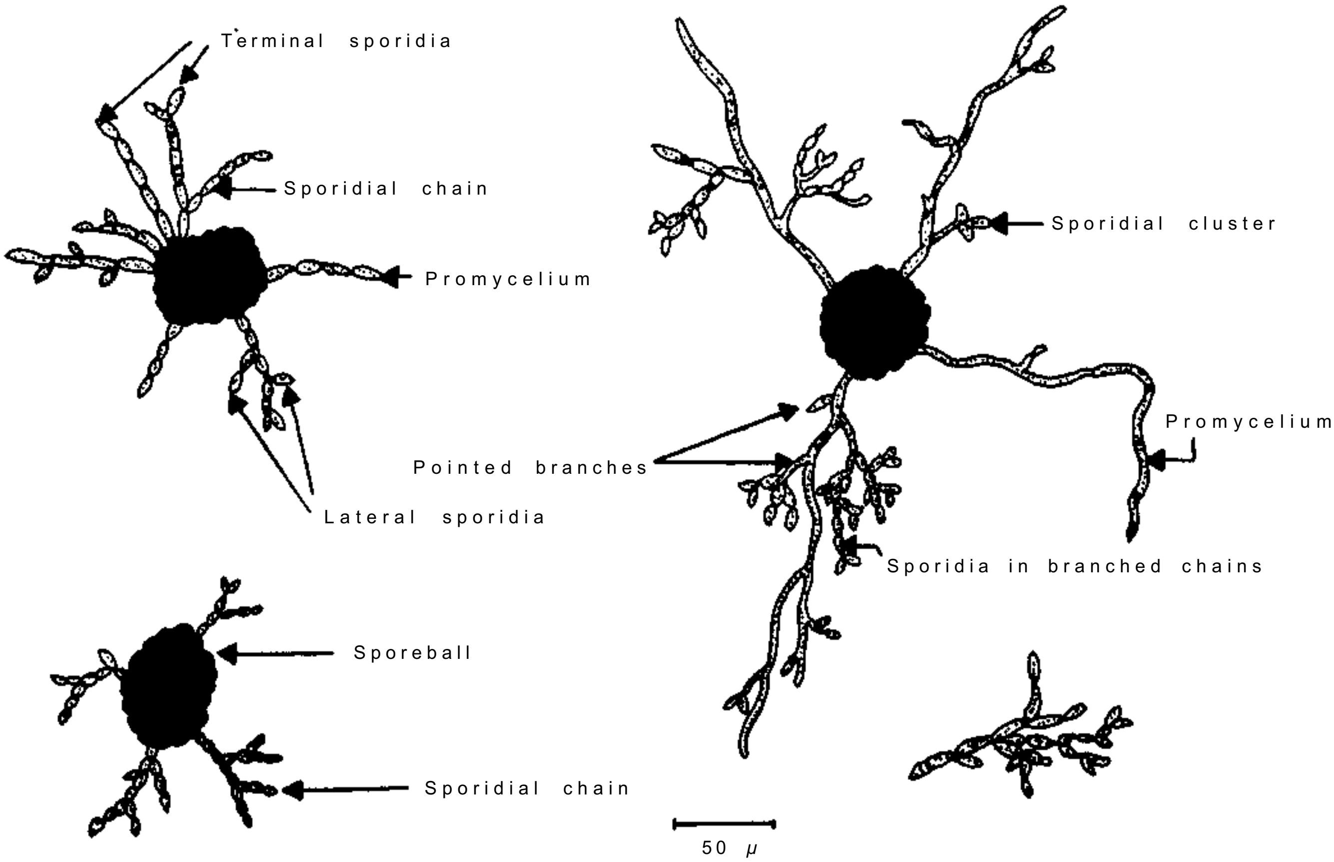


Figure 4. Patterns of teliospore germination in *Tofyposporium penicillariae.*

Table 4. Smut severity and seed set in five pearl millet lines following various inoculation and pollination treatments in field and screenhouse experiments, ICRISAT Center, 1982.

	Treatment[1]							
	Inoc., no poll.		Inoc., poll.		No. inoc, poll.		No inoc, no poll.	
Experiment and line	Smut severity(%)	Seed set(%)	Smut severity(%)	Seed set(%)	Smut severity(%)	Seed set(%)	Smut severity(%)	Seed set(%)
Field experiments								
ICH 220[2]	25±5.3	<1	1 ±0.1	82±3.8	0	85 ± 2.6	0	0
5054 A[3]	43 ± 2.5	<1	4 ± 0.7	76±1.9	0	83±1.0	0	< I
Screenhouse experiments[4]								
BJ 104	88±1.3	<1	8 ± 2.1	74 ± 4.2	0	91 ±1.4	0	15 ± 6.8
BK 560	77±5.6	<1	21 ±4.2	71 ± 4.3	0	86 ± 2.4	0	22 ± 8.7
5141 A	74 ± 5.3	0	32 ± 3.4	45 ± 8.3	<1	86 ± 2.2	1±0.9	1
5054 A[5]	43 ± 4.1	5±2.7	2 ± 0.5	84 ± 3.2	0	90 ±1.4	0	0

1. In each treatment inoculations were at the boot-leaf stage and pollinations at full stigma-emergence stage, 5-8 days after inoculation.
2. Based on observations of 20 inflorescences/treatment.
3. Based on observations of 100 inflorescences/treatment.
4. Based on observations of 10 inflorescences/treatment.
5. A separate experiment conducted without high humidity.

pores aggregated in balls varied from 200 to 1400. Teliospores were mostly circular and 7 to 12 μ. in diameter. Maximum germination of teliospores occurred at 30°C but different patterns of germination were observed (Fig. 4). Cultural characters of the pathogen grown on different media varied widely. The fungus grew well 3 to 5 days on potato/carrot agar at 35°C and its growth remained purely sporidial even after repeated subculturing. Sporidia were borne on promycelia, laterally and/or terminally, and were reproduced by budding in chains (Fig. 5). Sporidia were spindle-shaped and 8 to 25 μ long. Sporidial inoculum was effective for large-scale smut screening.

Effects of pollination on smut development. In field and screenhouse experiments, pollination of inflorescences of three pearl millet F_1 hybrids and two male-sterile (ms) lines with fresh viable pollen 5 to 8 days after inoculation with a *T. penicillariae* sporidial (suspension about 10^6 sporidia/ml) reduced smut severities significantly compared with the inoculated, nonpollinated check (Table 4). Smut development was not significantly reduced in a ms line after pollination of inoculated inflorescences with pollen of low viability (Table 5).

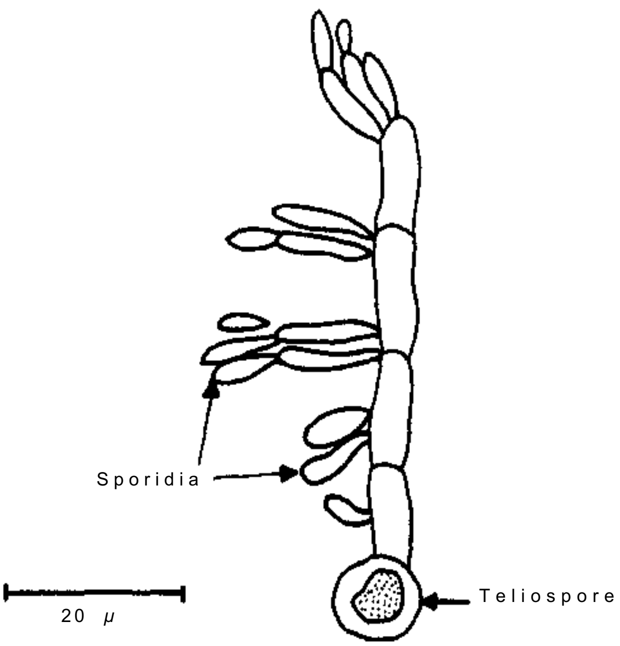


Figure 5. A germinated teliospore of *Tolyposporium penicillariae*.

The results indicate that to obtain high smut infection, inoculated inflorescences must be protected, by covering with bags, from pollination.

Table 5. Effects of inoculation and pollination with low-viability pollen (LVP) and viable pollen (VP) on smut development and seed set in a pearl millet male-sterile line (5054-A), ICRISAT Center, 1982.

Treatment[1]	Smut severity (%)[2]	Seed set (%)[2]
Inoc, no poll.	81 ± 3.1	0
Inoc, poll, with VP	2 ± 0.4	84 ± 4.3
Inoc, poll, with LVP	68 ± 5.8	4 ± 2.4
No Inoc, poll, with VP	0	83 ± 3.2
No inoc, poll, with LVP	0	10 ± 4.6
No inoc, no poll.	0	< 1

1. In each treatment inoculation was at the boot-leaf stage and pollination, at the maximum stigma-emergence stage, 5-8 days after inoculation.
2. Mean of 10 inflorescences/treatment.

Identifying and Using Disease Resistance

Identifying and using resistance to DM, ergot, smut, and rust continued as a major activity. As in previous years, large-scale field screening for DM, ergot, and smut was conducted at ICRISAT Center and for rust at Bhavanisagar. The multilocational testing of sources of resistance identified at 1CRISAT Center was continued in cooperation with ICRISAT cooperative program staff in various African countries and in India.

All trials of the All India Coordinated Millet Improvement Project (AICMIP) were screened for resistance to DM, ergot, and smut. Breeders and pathologists worked together in the continuing program ofusing DM resistance, in efforts to transfer ergot resistance into hybrid seed parents, in using smut and rust resistance, and in studying the genetics of disease resistance.

Downy Mildew

Developing a precise inoculation technique. We conducted several experiments to develop a laboratory/glasshouse technique to reliably screen pearl millet for DM resistance. In these experiments, we classified potted seedlings into six growth stages: Stage 1, seedlings <5 mm above soil surface and covered with plumule leaves; Stage 2, seedlings >5 mm but <1 cm above soil surface, first leaf still folded; Stage 3, seedlings > 1 cm above soil surface, first leaf still folded; Stage 4, first leaf beginning to unfold forming cup-like structure; Stage 5, second leaf beginning to unfold forming cup-like structure; and Stage 6, third leaf beginning to unfold forming cup-like structure.

By staggering the planting, we inoculated all stages at the same time. Individual seedlings were inoculated with viable sporangia suspended in water at 25 µl/ seedling with an Agla Micrometer Syringe (Wellcome). Inoculum, placed at the tips of the seedlings, rolled down to the base, covering the entire seedling surface. The seedlings' susceptibility decreased with age, with susceptibility maximum when seedlings were less than 1 cm above ground (Stages 1-3, Table 6).

Table 6. Downy mildew incidence on pearl millet NHB 3 seedlings inoculated with sporangia at six growth stages, ICRISAT Center, 1982.

Inoculation stage	Plant Nos.	Downy Mildew[1] (%)
1. <0.5 cm long	283	90.0 a[2]
2. 0.S to 1 cm long	251	85.6 a
3. > 1 cm long, first leaf still folded	213	84.9 a
4. 1st leaf unfolded	276	64.1 b
5. 2nd leaf unfolded	233	33.4 c
6. 3rd leaf unfolded	76	6.1 d
Not inoculated (control)	441	0

1. Mean of two tests except in the case of 3rd leaf unfolded.
2. Figures followed by the same letter are not significantly *(P=0.05)* different, based on statistic Z (standard normal deviate) used for comparing two binomial proportions.

Table 7. Mean downy mildew severities (%) of 34 pearl millet entries and three standard checks evaluated in the IPMDMN 2 to 7 years from 1976 to 1982 at indicated locations in India and West Africa.

Entry	Location	1976	1977	1978	1979	1980	1981	1982
SDN-503	Nigeria	0.6	1.3	2.7	2.5	8.0	9.0	8.0
P-7	Mali	5.5	1.7	3.4	3.0	9.0	6.0	5.6
700251	Nigeria	3.1	1.8	2.2	1.3	9.0	6.0	6.0
700516	Nigeria	2.1	3.0	2.3	0.8	7.0	5.0	3.0
700651	Nigeria	1.3	3.0	4.1	0.9	10.0	6.0	4.0
IP-1930	ICRISAT Center	-	-	-	2.0	8.0	2.0	-
EB-83-2	ICRISAT Center	-	-	-	1.5	6.0	5.0	-
IP-2058	Nigeria	-	-	-	0.7	9.0	8.0	-
MPP 7147-2-1	New Delhi	-	-	-	1.4	7.0	5.0	6.4
J-1486 x 700787-2-10	ICRISAT Center	-	-	-	0.9	7.0	5.0	-
SSC-7218	ICRISAT Center	-	-	-	0.1	7.0	4.0	-
NC-7158	ICRISAT Center	-	-	-	1.5	7.0	2.0	-
EB-18-3-1	ICRISAT Center	-	-	1.8	1.0	7.0	2.0	-
SDN-347-1	Nigeria	4.7	3.0	4.1	2.6	-	-	-
SDN-305	Nigeria	3.2	5.0	-	-	-	-	-
PHB-14	Ludhiana	4.5	7.7	-	-	-	-	-
BK-560	New Delhi	8.1	9.1	-	-	-	-	-
J-1188	Jamnagar	5.3	4.8	-	2.3	-	-	-
ICH-190 (111A x E298-2)	ICRISAT Center	-	2.7	5.6	-	-	-	-
P-10	Mali	-	3.1	3.9	1.4	-	-	-
114 IR	Senegal	-	4.0	6.3	6.1	-	-	-
T-128-3 x 700404-1-5-5	ICRISAT Center	-	-	-	0.4	8.0	-	-
700619	Nigeria	-	-	-	3.0	12.0	-	-
EB-79-2-2 x EB-59-3-1	ICRISAT Center	-	-	-	2.2	9.0	-	-
IP-2037	Nigeria	-	-	-	1.3	10.0	-	-
ICM-165 [11A x SC14 (M)]	ICRISAT Center	-	-	-	1.5	8.0	-	-
700706	Nigeria	-	-	-	-	9.0	3.0	-
E-298-2-1-8	ICRISAT Center	-	-	-	-	5.0	3.0	3.7
700546	Nigeria	-	-	-	-	7.0	6.0	7.1
700512	Nigeria	-	-	-	-	6.0	3.0	2.9
SDN-496	Nigeria	-	-	2.9	2.1	-	-	-
SDN-714	Nigeria	-	-	-	-	6.0	6.0	4.5
ICH-226 [5141A x (J1623 x 70049-2-6-2)]	ICRISAT Center	-	-	-	-	11.0	6.0	-
NC-7174	ICRISAT Center	-	-	-	0.9	8.0	3.0	-
J-1593 [a]	Jamnagar	-	27.9	13.5	8.1	17.0	15.0	-
BJ-104 [a]	New Delhi	-	13.6	-	12.5	21.0	10.0	17.4
7042 [a] (unselected)	Chad	-	-	-	58.3	63.0	68.0	44.4

a. Standard checks.

This technique is superior to other known inoculation techniques (seedling-dip, spraying, putting germinating seeds on leaves with profuse asexual sporulation) because it resembles natural inoculation yet permits uniform inoculum. We use the technique to screen all key-breeding material and to confirm field-identified resistance to downy mildew.

Resistance screening at ICRISAT Center. Using the infector-row screening technique, we screened approximately 7000 breeding lines in the field for DM resistance during the 1980/81 postrainy season and the 1982 rainy season. Almost all of our breeding material now carries acceptable DM resistance, after screening two seasons each year.

We screened 449 more germplasm accessions originating from Sudan, Botswana, Zimbabwe, Zambia, South Africa, Togo, Niger, and Upper Volta; 192 were DM free and 189 showed less than 10% DM.

We also screened 193 entries from the AICMIP. Five hybrids (MBH 133, MBH 134, MBH 135, MBH 136, and MBH 151) and one population (DEC 1) were DM free. Many hybrids and population entries had less than 10% DM.

Multilocational testing. Multilocational testing continued to be invaluable in identifying stable resistance and locating nonspecific resistance.

The 150-entry, Pre-International Pearl Millet Downy Mildew Nursery (Pre-IPMDMN) was tested only at ICRISAT Center. Under severe DM pressure, 48 entries were DM free, and 73 developed less than 10% DM. The DM-free entries will be tested in the 1983 IPMDMN.

The 45-entry IPMDMN was sent to cooperators at 14 locations in India and West Africa. Data were received from 12 locations. No entry was DM free at all locations; however, six entries (P 93, P 100, ICH 415, P 433, P 1930, and 700516) developed less than 10% DM at all locations.

Downy mildew reactions of 37 entries tested in IPMDMN for 2 to 7 years (1976-82) at many locations in India and West Africa are presented in Table 7. Clearly, we now have many sources of stable DM resistance.

Development of DM resistance. The study initiated in 1979 to develop resistance in IP 7042, a highly susceptible landrace cultivar from Chad, was concluded. In 1982 we raised 148 S_5 progenies in the DM nursery; 18 showed no DM and 45 showed high DM resistance (< 10% DM). Also 18 progenies were either DM free or had less than 10% DM in S_3, S_4, and S_5 generations (Table 8). The first six in the table showed all characters typical of 7042. One progeny 7042-3-1-2-2-2 showed less than 10% DM at all locations in India in the 1982 multilocational test. Variabilities for rust resistance and for several other characters, including plant height (extremely dwarf to tall), leaf size and shape, earhead length, and pollen color also were observed.

The results demonstrate that when a useful cultivar shows increasing DM susceptibility, it probably can be "renovated" by reselection of residual resistance. The information is now being used to develop resistance in parents of BJ 104, the most popular hybrid in India, which is becoming DM susceptible.

Ergot

Resistance screening. During the summer and rainy seasons of 1982 we screened more than 2500 entries for ergot resistance under different screening phases at ICRISAT Center.

Identifying resistance. To obtain ergot resistance in new backgrounds, we further screened 129 S_1 germplasm lines from Tanzania, 127 S_2 from Togo, and 18 S_2 from Ex-Bornu. All the Tanzanian lines were highly susceptible to ergot (>30% mean severity), but about 4% of Togo and 11% of Ex-Bornu lines showed < 10% severity (Table 9). We selected 83 single plants showing adequate selfed seed set and ergot resistance (<5%) for further evaluation.

Multilocational testing. The 29-entry, 1982 International Pearl Millet Ergot Nursery

Table 8. Downy mildew incidence (S_1-S_5) and rust incidence (S_5) in 18 best performing IP 7042 pearl millet progenies grown in the DM-nursery, ICRISAT Center, postrainy season 1981/82.

Pedigree	Downy mildew incidence (%)					Rust incidence (%)
	S_1	S_2	S_3	S_4	S_5	S_5
7042-3-1-2-2-2	46	10	6	1	0	10
7042-11-1-2-13-1	33	38	9	8	4	25
7042-11-1-12-4-1	33	38	8	0	0	5
7042-11-1-12-4-2	33	38	8	0	0	25
7042-11-1-12-4-3	33	38	8	0	0	25
7042-11-1-12-4-5	33	38	8	0	5	25
7042-3-1-2-2-1	46	10	6	1	0	10
7042-3-1-2-6-1	46	10	6	0	4	0
7042-3-1-2-6-2	46	10	6	0	0	5
7042-3-1-2-6-3	46	10	6	0	1	0
7042-11-1-2-2-1	33	37	9	9	5	40
7042-11-1-2-2-3	33	38	9	9	9	25
7042-11-1-2-13-2	33	38	9	8	1	40
7042-11-1-2-13-3	33	38	9	8	1	5
7042-11-1-2-13-4	33	38	9	8	0	25
7042-11-1-2-13-5	33	38	9	8	7	40
7042-11-1-2-13-6	33	38	9	8	5	10
7042-11-1-12-4-4	33	38	8	0	0	25
Susceptible check (NHB-3)[a]	62	37	53	84	72	40

a. Mean of all indicator lines.

(IPMEN) was tested at seven locations in India and one in Nigeria. Although no entry was ergot free at all locations, 13 showed high resistance with across-location mean severities of not more than 1% and maximum severity not more than 5% at any location. Another 9 entries had across-location mean severities between 2 and 5% compared with the susceptible check's 65% severity.

At Samara, where most of the 1981 IPMEN entries were recorded as highly susceptible, 25 of 29 IPMEN entries had < 10% mean severity in 1982; 8 entries tested both years had 13 to 46% severity in 1981 but < 6 % in 1982, although disease pressure was higher in 1982 (83% on susceptible check) than in 1981 (68% on susceptible check) (Table 10). Wider testing in Africa will be needed to determine if the present sources of ergot resistance (all developed at ICRISAT Center by pedigree selection following crosses between ergot low-susceptible lines) can be effective in that continent.

Developing resistance. The process of developing ergot-resistant lines, initiated in 1977, was continued. Selecting and selfing progenies from several sets of crosses between less susceptible plants from different germplasm sources continued.

The first set of crosses was advanced to F_8 generation where most lines appeared to be stabilized for ergot reaction and phenotypic uniformity. During the 1982 rainy season, we evaluated 32 F_8 line bulks in a replicated trial at ICRISAT Center and Aurangabad, India, and 159 F_8 line bulks in another replicated trial at the same two locations; 77% of the lines have shown

< 10% mean ergot severity (Table 9). We evaluated more than 1600 lines in F_3, F_4, F_5, and F_6 generations during the summer and rainy seasons, and 1270 (77%) showed high ergot resistance; we selected 1604 ergot-resistant individual plants with selfed seeds for further evaluation.

To test the stability of their resistance, we will include the best of ergot-resistant lines selected from these trials in the 1983 IPMEN.

Using resistance. The 1982 tests again confirmed the recessive nature of resistance to ergot; so resistance must be introduced into both hybrid parents. We thus continued efforts to incorporate ergot resistance in B lines and their counterpart ms A lines. Fortunately we have seven ergot resistant lines that are maintainers on 5054-A, 5141-A, and ms 81-A, which are being used in a backcross program to develop ergot resistance in A lines. Twenty-two F_2 populations, 111 F_3, 51 F_4, and 48 F_5 lines from crosses between B lines x ergot-resistant lines were evaluated. All 22 F_2 populations were highly susceptible, but ergot-resistant segregants were identified in F_3, F_4 and F_5 lines (Table 9). The results indicate that ergot resistance may be transferred in ms lines by backcrossing F_3 or F_4 lines.

Table 9. Number of pearl millet lines in various categories of mean ergot severity and ergot resistant plant selections in (he ergot resistance screening nurseries during summer (S) and rainy (R) seasons, ICRISAT Center, 1982.

Material	Season	No. of entries	No. of entries with mean ergot severity				No of single plants selected
			<10%	11-20%	21-30%	>30%	
Ciermplasm lines[1]							
Tanzania	S	129 (S_1)	0	0	0	129	26
Togo	R	127 (S_2)	5	1	II	110	41
Ex-Bornu	R	18 (S_2)	2	1	I	14	16
Development of resistance[2]							
F_3 lines	S	167	72	55	17	23	199
F_4 lines	R	685	534	96	41	14	763
F_5 lines	S	310	229	38	34	9	483
F_6 lines	R	48.1	435	24	10	14	159
F_8 line bulk	R	159	122	21	6	10	.5
F_8 bulk trial	R	32	26	2	1	3	-
Use of resistance[1]							
Hybrid I (ER x ER)	R	49	44	4	1	0	-
Hybrid II (ELS x ER)	R	55	25	16	7	7	-
F_2 pop. (B x EL S-1)[4]	S	22	0	0	0	22	111
F_3 lines (B x ELS-1)	R	111	64	18	15	14	67
F_4 lines (B x BLS-11)	S	51	5	6	5	35	48
F_5 lines (B x FLS-11)	R	48	12	8	7	21	35
ER maintainers[5]	R	64	62	0	1	1	-

1 Based on 10-20 inoculated inflorescences/entry.
2. Based on 20-40 inoculated inflorescences/entry in 2 replications.
3. Based on 10 inoculated inflorescences/entry in 2 replications.
4. Based on more than 200 inoculated inflorescences/populations.
5. - indicates selections not made.
B = B line.
ER = Ergot resistant (stable lines).
ELS = Ergot low susceptible.

Table 10. Performance of the eight IPMEN entries in 1981 and 1982 at one West African and three Indian locations.

	Ergot severity[2] (%) at							
	Samaru		Aurangabad		Jamnagar		ICRISAT Center	
Entry[1]	1981	1982	1981	1982	1981	1982	1981	1982
ICMPE 134-6-9	46	< 1	8	1	< 1	1	< 1	1
ICMPE 134-6-11	43	< 1	8	5	< 1	1	<1	
ICMPE 134-6-41	35	< 1	9	5	<1	<1	<1	
ICMPE 134-6-34	35	< 1	8	2	1	1	1	
ICMPE 134-6-25	44	1	10	1	<1	0	<1	<1
ICMPE 13-6-27	18	6	20	1	7	1	5	
ICMPE 13-6-30	33	1	2S	1	4	1	3	2
ICMPE 34-1-10	13	2	13	4	4	7	4	13
Susceptible check	68	83	60	97	41	58	99	98

1. ICMPE = ICRISAT millet pathology ergot-resistant lines.
2. Based on 20-40 inoculated inflorescences/entry in 2 replications.

Smut-resistant pearl millet heads at left contrast with those from a normal, susceptible line in ICRISAT's inoculated screening nursery. In our 28-entry multilocational testing for smut across five locations, we identified 15 entries with < 1% mean severity (<2% at any location) and 13 others with < 7%, compared with 49% in the control.

Smut

Resistance screening. After an effective field screening technique was developed in 1981, the major smut resistance screening was shifted from Hissar to ICRISAT Center in 1982. Sprinkler irrigation let us screen about 3000 entries in a 2-ha smut nursery during the 1982 rainy season.

Identifying resistance. During the 1982 rainy season, 463 smut-resistant (SR) single plant selections from the 1981 rainy season screening and 34 entries in the pearl millet smut nursery (PMSN) were evaluated in a replicated trial at the ICRISAT Center smut nursery. More than 90% of the single plant selections and all the PMSN entries showed high smut resistance (<10% mean severity), compared with 72% in the susceptible check, and 462 smut-resistant selfed plants were selected for further evaluation (Table 11).

Multilocational testing. The 28-entry 1981 IPMSN was evaluated at three Indian and two West African locations. Fifteen entries showed mean smut severity of < 1 % across locations with maximum of 2% at any one location; the

Table 11. Number of pearl millet lines in various categories of mean smut severity and smut resistant stent selections made in the smut resistance screening nursery, ICRISAT Center, rainy season 1982.

Material	No. of entries	No. of lines with mean smut severity (%)				No. of single plants selected
		<10	11-20	21-30	>30	
Identification of resistance[1]						
Smut resistant selections 1981	463	433	17	8	5	324
PMSN	34	34	0	0	0	138
Development of resistance[1]						
F_3 (SR x SR) lines	133	133	0	0	0	157
F_4 (SR x SR) lines	112	106	4	1	1	142
SR Tall sel. F_5	487	467	21	3	2	552
SR Med. tall F_5	486	477	4	3	2	695
SR Dwarf F_5	17	16	1	0	0	35
SR Ag. elite F_5	29	29	0	0	0	150
Use of resistance[2]						
F, test hybrids	17	0	0	3	14	-
SR Comp. C_2 cycle	712	615	78	17	2	640
SR Synthetics	2	2	0	0	0	-[3]
F_1 (81 B x SR)	88	43	13	8	24	-
F_5 (23 D_2 B x SR)	95	50	13	15	17	-
SR Pollinators	14	10	3	1	0	-

1. Based on 10-40 inoculated inflorescences.
2. Based on 5-40 inoculated inflorescences.
3. Selections not made.
PMSN = Pearl Millet Smut Nursery.
SR = Smut resistant.

remaining 13 entries had mean smut severities between 1 and 7% compared with 49% in the check. Two entries (SSC-FS 252-S-4 and ICI 7517-S-1) have shown stable resistance across locations over 5 years of testing; both are being used in the ICRISAT Center breeding program to develop smut-resistant varieties and hybrids.

Developing resistance. To obtain increased resistance to smut, we intermated several smut-resistant lines and after pedigree selecting at each generation of screening, we selected progenies with high smut resistance and good agronomic traits. During the 1982 rainy season, we evaluated 1264 smut resistant. individual plant selections as F_3, F_4, and F_5 progenies; 1228 lines (97%) showed high smut resistance (< 10% mean severity). They were categorized into different height groups—tall, medium tall, and dwarf, and 40 smut resistant lines with good agronomic traits were identified. More than 1700 smut-resistant plants were selected (Table 11) for evaluation at F_4 and F_5 generations in 1983.

Using resistance. We evaluated 17 F_1 test hybrids (ms lines x SR. lines), 712 half-sib progenies of smut-resistant composite (SRC) C_2 cycle, 2 synthetics, 88 F_1s (81B x SR), 95 F_5 lines (23DB x SR), and 14 SR pollinators for smut resistance.

All 17 test hybrids WERE susceptible (> 20% smut severity), but 615 (86%) of the composite progenies, the 2 synthetics, 10 pollinators, 43 of the 88 F_1s (81B x SR) and 50 of the 95 F_5 (23D_2B x SR) showed <10% smut severity (Table 11). From the SRC half-sib progenies about 300 S_1s have been developed and will be tested for performance and smut resistance, to identify the best for recombination.

With a reliable screening technique available, it appears possible to transfer smut resistance into maintainer (B) lines and thus produce resistant ms (A) lines. It also appears feasible to increase resistance in varieties and synthetics in a relatively few cycles.

Rust

Initial screening. Germplasm accessions (542) originating from Mali, Uganda, Nigeria, Niger, Senegal, Lebanon, and USA were initially screened at Bhavanisagar, a rust hot spot. Twenty-one of the 542 accessions were rust free, and 311 had less than 10% rust. The remainder developed 25 to 65% rust.

Multinational testing. The 45-entry, 1982 IPMRN was sent to cooperators at seven India locations. Results, received from only four, showed rust pressure most severe at Pudukkotai and moderate at Kovilpatti, Bhavanisagar, and Hissar. No entry was rust free at all locations, but several, including 700481-21-8, 700481-22-8, IP-537, IP-2084-1, 700481-7-5, IP-2084-1, D212 PI, and collection-91, showed stable rust resistance.

Screening for Multiple Disease Resistance

Screening pearl millet germplasm lines and breeding materials simultaneously for resistance to downy mildew (DM), ergot, smut, and rust was initiated during the summer 1982. The methodology involved space planting (20 cm between plants on 75-cm rows) test lines in the DM nursery, where DM already was well established on infector rows. DM scores were taken 30 days after emergence (DAE); final scores, 45 DAE. In selected DM-free plants, two tillers were inoculated—the first with ergot, the second with smut. Observations for ergot and smut severity were recorded 20 days after inoculation and selfed seed were selected from plants resistant to all four diseases listed.

During the 1982 summer, 303 entries consisting of germplasm lines from Togo (178 S,s), Ex Bornu (45 S_1s), and entries from IPMDMN, IPMEN, IPMSN and IPMRN were screened. Hot, dry weather during March-April kept smut inoculations from being successful, but observations were recorded for DM, ergot, and natural rust incidence. Among the germplasm lines, only 17% of Togo lines and 22% of Ex-Bornu lines showed <10% ergot severity but most entries (94-100%) resisted DM and rust.

Again among the disease nurseries, few entries resisted ergot but 100% of the IPMEN entries resisted ergot; 85%, DM; and 100%, rust. Other nurseries had few entries with ergot resistance. The results indicate that although most of the lines resist DM and rust, only a few have resistance to ergot and their resistance, except in IPMEN entries, may or may not be stable over years (Table 12).

During the 1982 rainy season, 832 entries including A1CMIP trial entries, Ghana germ-

Table 12. Summary of the results of screening pearl millet lines for multiple disease resistance at ICRISAT Center, summer season (January-April) 1982.

Material	No. of entries	% entries with ≤10% incidence/ severity		
		DM[1]	Ergot[2]	Rust[3]
IPMDMN	30	100	0	97
IPMRN	10	70	20	100
IPMEN	20	85	100	100
IPMSN	20	85	30	95
Ex-Bornu (S_1)	45	100	22	100
Togo (S_1)	178	94	17	99

1. Incidence based on total and infected plants observed in 2 replications, 2 rows/entry per replication.
2. Severity based on mean of 40 inoculated heads in 2 replications.
3. Severity based on mean of 2 replications, 2 rows/entry per replication.

plasm lines, ICRISAT breeding lines, and disease nurseries (IPMDMN, IPMEN, and IPMSN) were evaluated. DM and smut resistances were widespread but ergot resistance was rare except in IPMEN entries (Table 13). Ergot, smut, DM, and rust reactions of some of the ergot-resistant entries in 1981 and 1982 are presented in Table 14.

Results of two seasons of multiple-disease screening indicate that because ergot resistance is difficult to find and stabilize, the strongest selection pressure should operate for ergot resistance first and then for other diseases.

Alternate Control Methods

We conducted several glasshouse and field experiments to determine the efficacy of metalaxyl, a systemic fungicide, in curing DM-infected plants, we sprayed systemically infected plants of several ages with several concentrations of the fungicide. Plants as old as 40 days recovered and produced healthy leaves within 7 days of spraying. But spraying should be before panicles initiate or infected plants produce characteristically deformed "green ear" heads.

In glasshouse tests 125 ppm (product) was the

Table 13. Summary of results of screening pearl millet lines for multiple disease resistance at ICRISAT Center, rainy season 1982.

		% entries with <10% incidence/severity		
Material	No. of entries	DM[1]	Ergot[2]	Smut[3]
A1CM1P				
IPMHT-1	21	62	0	14
APMHT-II	19	74	0	21
IPMPT-IV	15	33	0	60
APMPT-V	17	64	0	35
Male Sterile lines	106	53	1	35
Others	18	50	0	44
Germplasm lines				
Ghana	123	96	2	94
ICRISAT breeding trials				
PMST	25	88	0	84
PMHT	25	84	0	32
PMHT(P)	25	60	0	-[4]
DSC Bulks	16	94	0	87
APVT	24	87	0	71
MDI	247	80	4	85
F_5 Progenies (B x ERL)	49	92	25	83
Pathology trials				
IPMEN	29	93	79	100
IPMSN	28	86	3	100
IPMDMN	45	91	0	48

1. Incidence based on total and number of infected plants for each entry.
2. Severity mean of 10-20 bagged-inoculated heads.
3. Severity mean of 5-20 inoculated-bagged heads of same plants inoculated earlier with ergot. Since inoculations were made in later part of the dry season, smut development was not adequate on test entries.
4. - indicates not inoculated.

Table 14. Ergot, smut, downy mildew (DM), and rust reactions of some of the ergot resistant pearl millet entries, ICRISAT Center, 1981 rainy (R) and 1982 summer (S) and rainy seasons.

	Ergot sev. (%)			Smut sev. (%)		DM inc. (%)			Rust sev.(%)
	1981[b]	1982[d]		1981[b]	1982d	198[c]	1982[d]		1982[d]
Entry[a]	R	S	R	R	R	R	S	R	S
ICMPE 134-6-25	< 1	0	< 1	0	0	0	0	0	0
ICMPE 134-6-41	< 1	< 1	< 1	0	0	0	1	0	0
ICMPE 134-6-9	< 1	1	< o	0	-[c]	0	1	0	0
ICMPE 134-6-11	< 1	0	< 1	0	0	0	0	5	0
ICMPE 140-3	1	< 1	3	0	0	0	0	0	0
ICMPE 13-6-27	5	0	0	0	0	0	0	0	0
BJ-104 (Check)	83	67	94	54	48	32	5	51	40
WC-C75 (Check)	74	-	66	3	2	2	-	5	-

a. ICMPE=ICRISAT millet pathology ergot, derived from crosses J2238 x J2210-2 and J606-2 x J2238.
b. Based on 40 inoculated heads from two replications, both ergot and smut inoculations made on tillers of the same plant.
c. Based on DM reactions during the 1980/81 postrainy season in ICRISAT Center DM nursery.
d. Screening done in multiple disease nursery.
e. - indicates data not recorded/entry not included.

lowest fungicide concentration that permitted 100% recovery. But, in the field with sporangial inoculum present in abundance, at least 250 ppm (product) is required for acceptable control, which was significantly superior to seed treatment at 2g a.i./kg seed, recommended rate for field application (Table 15).

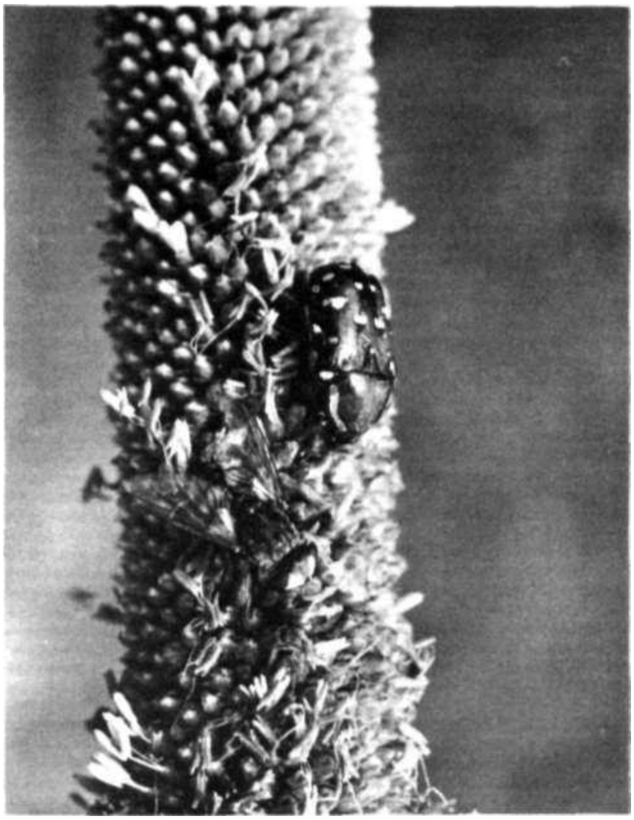
Insect Pests

In the pearl millet insect-observation plots at ICRISAT Center the past 3 years, we observed 83 insect species feeding on millet, 23 for the first time. Fortnightly observations on insect damage-population revealed that of the 83 insect

Table 15. Recovery (%) of systemically downy mildew-infected, 29-day-old pearl millet plants of IP 7042 and NHB-3 after spraying with metalaxyl (WP-2S) in DM-nursery conditions.

	Downy mildew %			
	IP 7042		NHB-3	
Treatments	Incidence	Severity	Incidence	Severity
1000 ppm	10.7	4.9	1.2	0.6
500 ppm	12.2	6.2	2.0	1.0
250 ppm	8.4	4.4	10.0	6.2
125 ppm	24.0	15.0	28.6	18.9
Seed treatment[1]	48.0	35.5	16.7	10.6
Unsprayed	85.8	79.9	87.0	79.9
SE ±	2.3	2.0	4.5	3.4

1. Seed was treated at 2 g a.i./kg seed.



Earhead chaffer. **Oxycetenia versicolor,** *one of the 83 insect species observed feeding on millets at ICRISAT Center.*

species observed, wireworms (*Gonocephalum* spp.), white grub (*Apogonia* sp.), shoot fly (*Atherigona approximata),* maize aphid (*Rhopalospiphum maidis),* leaf beetle (*Chaetonema minuta),* shoot bug (*Peregrinus maidis),* armyworm (*Mythimna separata),* earhead caterpillars (*H. armigera, Eublema silicula* etc.) and thrips (*Thrips* sp.) became serious.

Armyworm (*Mythimna separata*)

An analysis of 2 years of larval parasitism data showed fewer Hymenopteran parasites in pearl millet (<5%) than in sorghum (>25%), which helps explain the more extensive defoliation of pearl millet (Fig. 6). In an experiment with four weeding treatments (weed-free, Atrazine @ 0.5 kg/ha + one hand weeding, one hand weeding, and unweeded check), larval populations and leaf defoliation were higher in weedy plots (Fig. 7) because they shelter the larvae in the topsoil during the day. Grain yield correlated negatively with larval populations (r = -0.69), leaf damage (r = -0.71), and with weed dry weight (r = -0.94).

Head Caterpillar *(Heliothis armigera)*

Heliothis armigera is a serious pest on developing grain in pearl millet heads; up to 212 larvae/100 earheads have been observed with a maximum of 10 larvae/earhead during September. Larval population density can vary widely in one field, which must be considered in planning *Heliothis* experiments.

Biological Nitrogen Fixation

Acetylene Reduction Assay for Nitrogenase Activity

We improved the assays developed earlier (ICRISAT Annual Report 1975/76, p. 85; 1979/80. p. 66) for estimating nitrogenase activity of pearl millet.

Soil core assay. Nitrogenase activity of pearl millet hybrid NHB 3 plants grown in the field and estimated by our regular core assay at harvest was compared with that of plants grown with roots enclosed by the core from 15 days after planting (planted-core assay). Frequency distributions of nitrogenase activities are compared in Figure 8. Activities of most of the plants estimated by the regular core assay ranged from 0 to 20 nmol C_2H_4/plant per hr compared with 100 to 250 nmol C_2H_4/plant per hr, for the planted-core assay. Mean activity recorded for planted cores was 167 nmol C_2H_4/plant per hr, significantly higher than the regular cores' 18 nmol C_2H_4/ plant per hr.

As plants aged, activity of the regular cores declined more than that of planted cores. Earlier work had shown that activity of the core taken over the crown of the plant represented only 15 to 40% of the total activity associated with that plant (ICRISAT Annual Report 1976/77, p. 44) and that mechanical disturbances during collection and transport of the regular core reduced

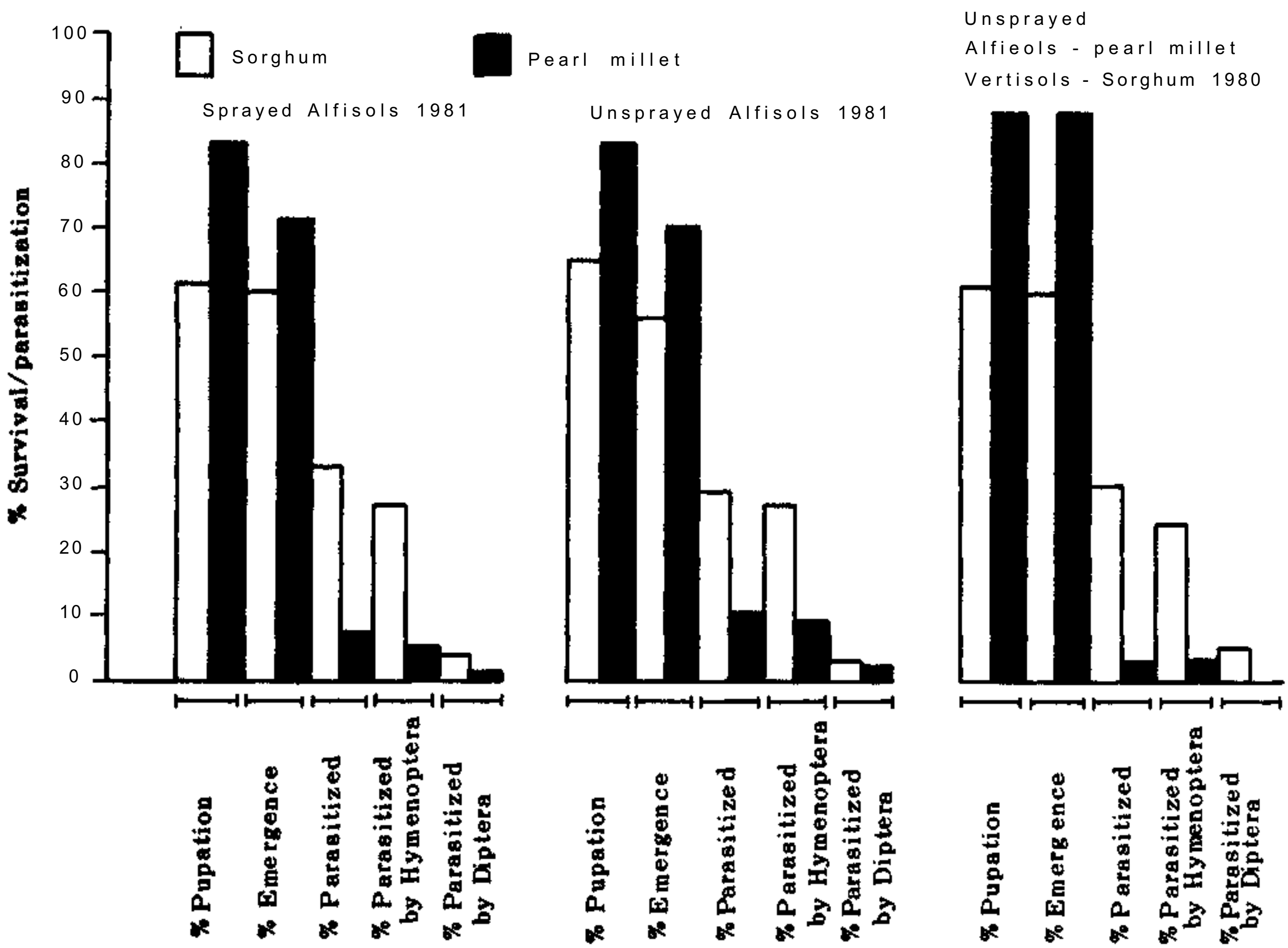


Figure 6. Larval survival and parasitization of *Mythimna separata* on sorghum and pearl millet in three environments, ICRISAT Center.

activity (ICRISAT Annual Report 1981, p. 64). So the higher activity of the planted cores may stem from higher concentration of roots in the core and less disturbance of the soil-root interface while preparing for the assay.

Intact-plant assay for pot-grown plants. Acetylene injected at the base of 6-liter, 20-cm deep pots of sand, sand soil, and vermiculite media diffused through the media within 1 hr so that the acetylene concentration in the space above and below the rooting media (except soil alone) was similar and remained so the next 5 hr (Fig. 9). For Alfisol soil, equilibration of injected gas was rapid initially, but was not complete by 6 hr. The effects of different root media on gas diffusion need to be taken into account when deciding how long to measure acetylene reduction. We measure acetylene reduction for soil media in pots 1 to 6 hr after acetylene is injected, but that is a less accurate measure than for the other media tested, because gas diffuses so slowly. Plants grown in an Alfisol soil or sand + FYM 97:3 w/w, grew significantly better than plants in N-free vermiculite or sand + soil. In a separate experiment with 61-day-old Ex-Bornu plants, we found more nitrogenase activity for the sand +3% w/w FYM (612 nmol C_2H_4/plant per hr) than for Alfisol soil (269 nmol C_2H_4/plant per hr).

Different mixtures of sand and farmyard manure were compared as growth media. Table 16 shows that 2 or 3% FYM supported the most nitrogenase activity, but 1 or 0.5% FYM supported relatively little activity. Plant growth increased as amount of FYM increased. Even

Table 16. Effect of indicated levels of farmyard manure (FYM) on total dry matter and nitrogenase activity associated with millet cv Ex-Bornu, 1CRISAT Center, 1982.

Treatment	Nitrogenase activity ($nmoles\ C_2H_4$/plant per hr)[1] 44 DAP	71 DAP	Total dry weight (g/plants)[2]
Sand:FYM (97:3 w/w)	593 ± 102	483 ± 194	32.6 ± 1.28
Sand:FYM (98:2 w/w)	542 ± 154	745 ± 235	27.7 ± 1.43
Sand:FYM (99:1 w/w)	86 ± 25	137 ± 39	10.4 ± 0.6
Sand:FYM (99.5:0.5 w/w)	106 ± 24	276 ± 73	5.5 ± 0.46

1. Average of 10 replications, moisture in pots adjusted to 60-70% water-holding capacity 1 day before assay as intact plants.
2. Plants harvested 71 days after planting (DAP), average of 10 replications.

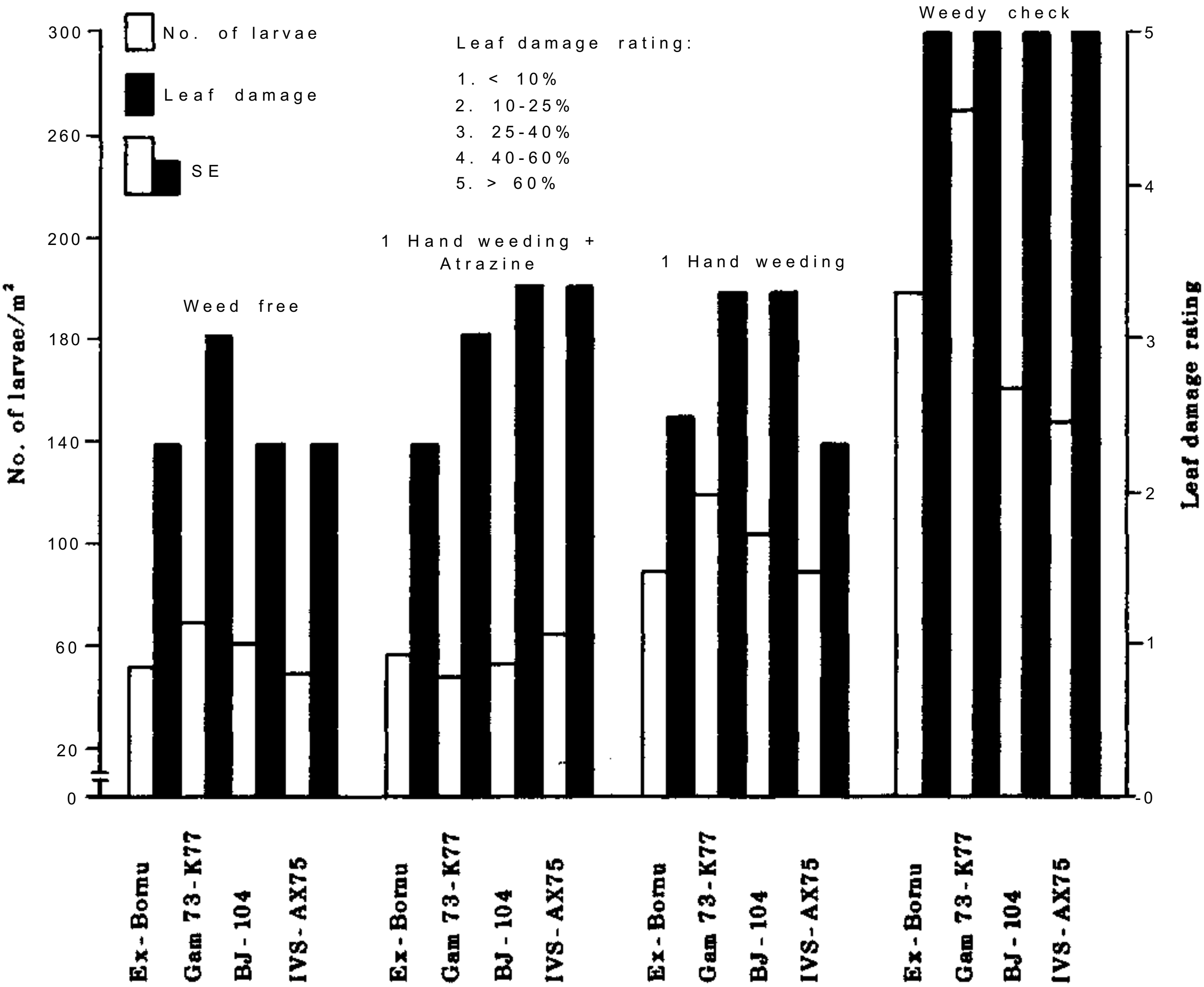


Figure 7. Effect of extent of weeding in four varieties of pearl millet on larval population and leaf damage by oriental armyworm, *Mythimna separata,* ICRISAT Center, 1981.

with 10 replicate plants the standard error for nitrogenase activity was large. Part of the variation in activity could be attributed to genetic variability in the Ex-Bornu population.

To test the effect of incubation temperature, we used 56-day-old plants in temperature-controlled water baths for 10 days before the assay; 34°C and 40°C supported nitrogenase activity the same but at root temperature of 29°C, nitrogenase activity was significantly smaller (Table 17).

Tube-culture assay technique. During 1982 we developed a tube-culture assay to estimate nitrogenase activity of millet seedlings in the

Table 17. Effect of incubation temperature on nitrogenase activity associated with millet cv Ex-Bornu plants, ICRISAT Center, 1982.

Temperature (°C)	Nitrogenase activity nmoles C_2H_4/plant per hr[1]
29 ± 2	195 ± 50
34 ± 1	694 ± 235
40 ± 0.5	634 ± 200

1. Average of 5 replications, plants grown in sand:FYM (97:3 w/w). The pots at 34 and 40° incubated in temperature-controlled water baths and conditioned at bath temperature for 10 days before the assay. For the 29° treatment, pots were in greenhouse with air temperature control.

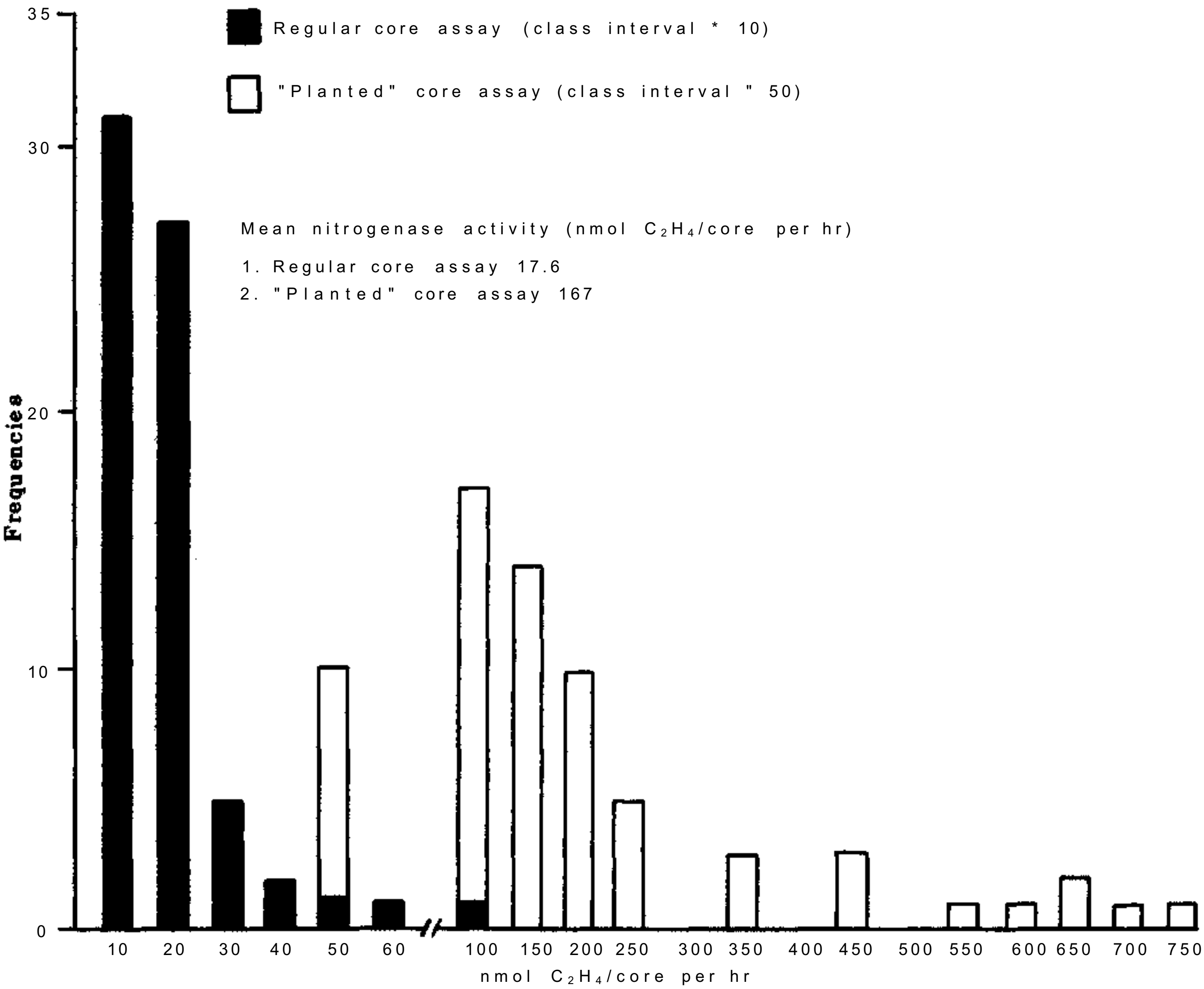


Figure 8. Frequency distribution of nitrogenase activity of millet hybrid NHB-3, expressed as nmol/plant per hr, for "planted'' cores and for regular cores.

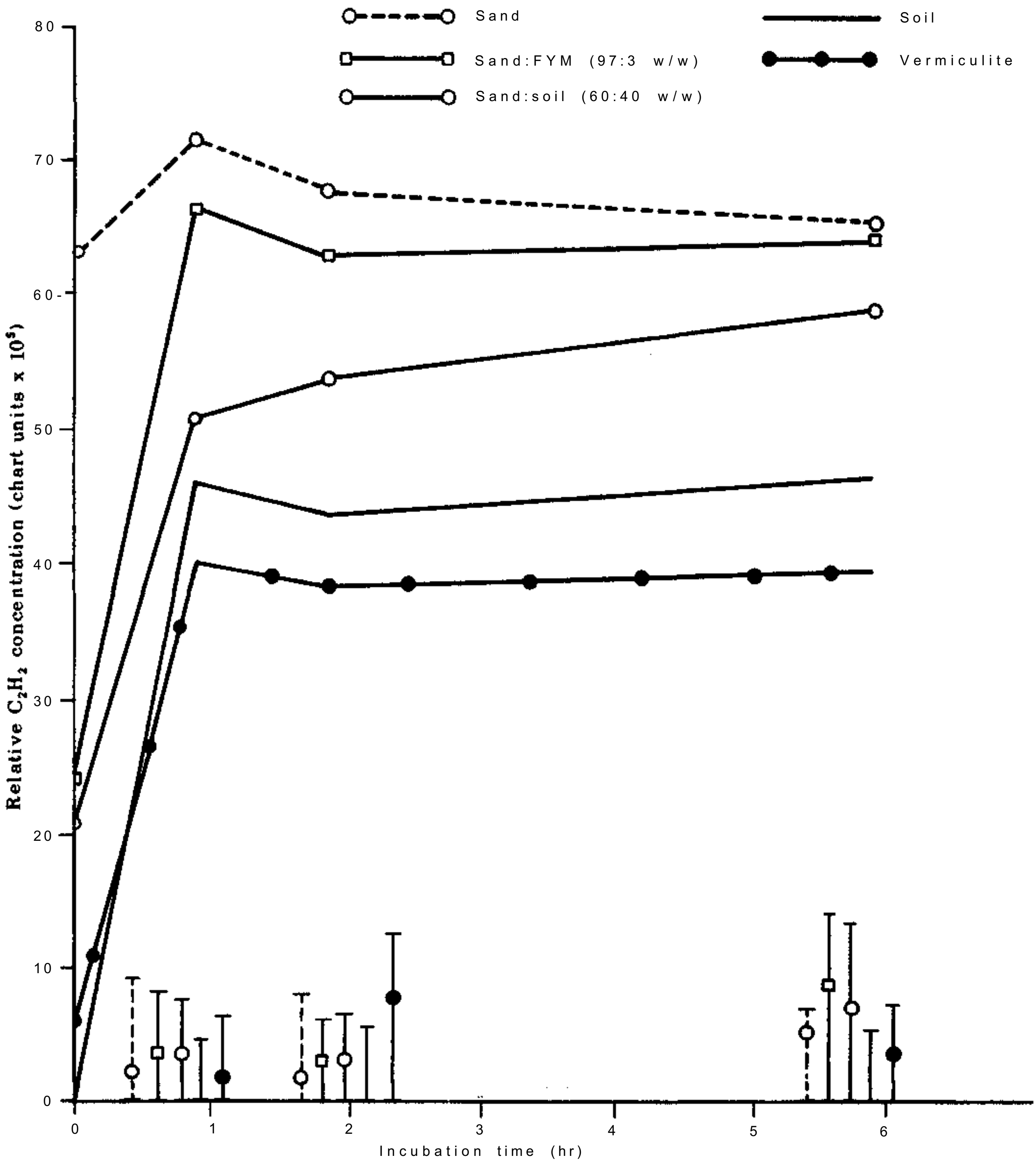


Figure 9. Pattern of acetylene gas diffusion through plastic pots filled with indicated growth media adjusted to 60-70% of water-holding capacity. Acetylene gas was injected at the bottom of the pot and gas samples were collected from tops of the pots.

greenhouse. The plants were grown in 20 cm x2.5 cm dia, 80-ml glass test tubes with a small tube attached to the side near the bottom (Fig. 10). The tubes were filled with 20 to 25 ml of growth medium, soil, sand, sand FYM, vermiculite, or nitrogen-free agar, then the tubes were covered and painted to keep light from the root medium. Plants were grown inside the tube, which was plugged with cotton wool until the assay, then with a rubber Suba Seal; the side tube was also closed with a Suba Seal. Acetylene gas, equivalent to 15% of the free volume in the tube, was injected through the bottom Suba Seal. Eleven lines of millet were sown and one control tube without seed inoculated with a rhizosphere extract of field-grown millet to provide a mixed inoculum.

Differences between cultivars in stimulating nitrogenase activity were apparent by 20 days after planting, and rankings were similar in different growth media. The technique was further improved by allowing the shoots to grow outside the test tube. At assay time a Suba Seal and silicone rubber were used to seal the gas phase around the root medium with the shoot remaining free in the air. This method again permitted differences to be detected between millet lines stimulating nitrogenase activity by 20 days after planting.

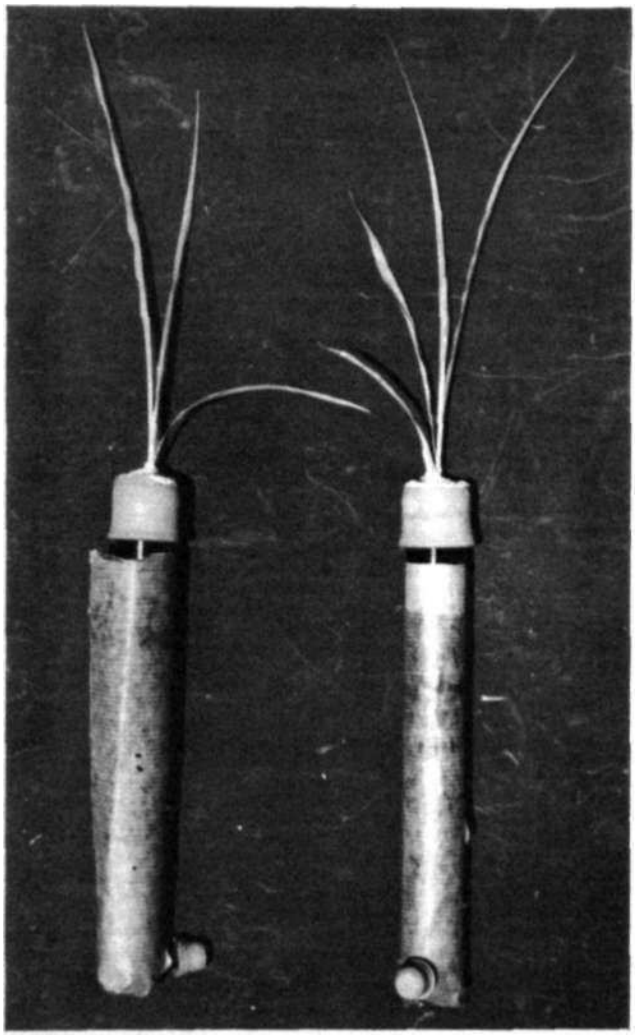


Figure 10. To estimate nitrogenase activity of intact millet seedlings in the greenhouse, we grew the plants in 80-ml glass tubes, 20 cm x 2.5 cm diameter.

Responses to Inoculation with Nitrogen-fixing Bacteria

We conducted a field trial with irrigation in the 1982 summer season, in an Alfisol soil containing 0.047% total nitrogen in the top 15-cm layer and 0.044% in the 15- to 30-cm layer. Millet cultivars IP 2787 and ICMS 7819 were inoculated with different N_2-fixing bacteria at sowing and again after seedlings emerged. The cultivars' responses to inoculation differed in both dry-matter production and grain yield (Table 18). Cultivar ICMS 7819 did not respond to inoculation but *Azospirillum lipoferum* increased IP 2787's grain yield 17%. In a further field experiment during the rainy season with three millet cultivars and five inoculum strains, and an inoculum-free control, inoculations again produced definite effects, with indications of strain x cultivar interaction (Table 19). Inoculation with either *A. lipoferum* or *Azolobacter chroococcum* increased yields of cultivars WC-C75 and IP 2787—with a mean increase of 27% for *A. lipoferum* and 19% for *A. chroococcum*—but cultivar ICMS 7703 was not responsive to those two inoculants. However, inoculation with *A. braziliense* decreased the yield of cultivar WC-C75, but not those of ICMS 7703 or IP. 2787. These results are similar to those obtained in Israel following inoculation of sorghum with *Azospirillum*.

Table 18. Effect of inoculation with nitrogen-fixing bacteria on dry-matter production and grain yield of pearl millet with irrigation, ICRISAT Center, summer season 1982.[1]

	Plant dry matter (kg/ha)			Grain yield (kg/ha)		
Inoculum	IP 2787	ICMS 7819	Mean	IP 2787	ICMS 7819	Mean
Azospirillum lipoferum[2]	1740	1810	1770	930	1360	1140
A. braziliense	1410	1930	1670	760	1240	1000
NBRE	1630	1910	1770	880	1230	1050
Not inoculated (control)	1550	1880	1670	830	1310	1070
SE	±113		±80	±29		±21
Mean	1580	1880		850	1280	
SE	±56			±3.6		
CV (%)	16			16		

1. 12 replications (net plot size 16.9 m^2). No nitrogen fertilizer applied. Each plot inoculated twice, once at sowing and 30 days later with 2.5 liters of liquid inoculum prepared by suspending in 25 liters of water, a 70-g peat culture with viable bacterial count of 10^8/g peat.
2. Strain 4 ABL obtained from Dr. J. Balandreau.

Mycorrhiza

Certain zygomycetous fungi form a symbiotic association with plant roots known as vesicular arbuscular mycorrhiza (VAM). The mycorrhiza associations improve plant growth mainly by increasing uptake of such relatively immobile soil nutrients as phosphorus. VAM also seem to enhance resistance to disease.

Mycorrhizal fungi have not been grown in the absence of plants. Using the perennial grass (*Cenchrus ciliaris*) as the host plant, we have

Table 19. Effect of inoculation with different nitrogen-fixing bacteria on grain yield of pearl millet, rainy season 1982.

	Grain yield (kg/ha)[1]			
Inoculum	IP 2787	ICMS 7703	WC-C75	Mean
Azospirillum lipoferum	2090	2110	2560	2250
Azospirillum lipoferum (1)[2]	2060	2010	2310	2130
Azotobacter chroococcum	2140	2110	2110	2120
NBRE	1870	1980	2070	1970
Azospirillum braziliense	1720	1760	1450	1650
Control (not inoculated)	1690	2030	1870	1860
SE		±203		±98
Mean	1930	2000	2060	
SE		±52		
CV (%)		22		

1. Average of five replications (net plot size 13.5m^2). No nitrogen fertilizer applied. Each plot inoculated twice, once at sowing and 30 days later with 2.5 liters of liquid inoculum prepared by suspending a 70-g peat culture packet with viable bacterial count of 10^8/g peat, in 25 liters of water.
2. Strain 4 ABL obtained from Dr. J. Balandreau.

isolated and multiplied large quantities of the major types of the symbiotic fungi, and now maintain strains of *Gigaspora calospora, G. margarita. Glomus mosseae, G.fasciculatum, G. fasciculatum* (E3 type), G. *epigaeum, G. macrocarpum,* and *Acaulospora* sp.

Our survey of pearl millet at ICRISAT Center showed that it forms mycorrhizal symbioses (Fig.11) with all four major genera of VAM fungi.

Pot-culture studies with sterilized soil and sand root media showed that mycorrhiza benefited plant growth. Of six cultures tested as inoculants, *Gigaspora calospora,, G. margarita,* and *Glomus fasciculatum* increased shoot dry matter 50% over the noninoculated control. One culture, E3, depressed growth. Tissue P concentration increased with VAM inoculation but with wide variation among isolates. The total uptake of phosphorus by plants inoculated with either *G. fasciculatum* or *Gigaspora margarita* was twice as large as that of noninoculated plants. Extent of root colonization by the isolates and plant dry-matter production correlated strongly (r = 0.77, df 34; $P \geq 0.05$) (Fig. 12).

The two best mycorrhizal isolates from the previous trial were compared with P fertilizing in

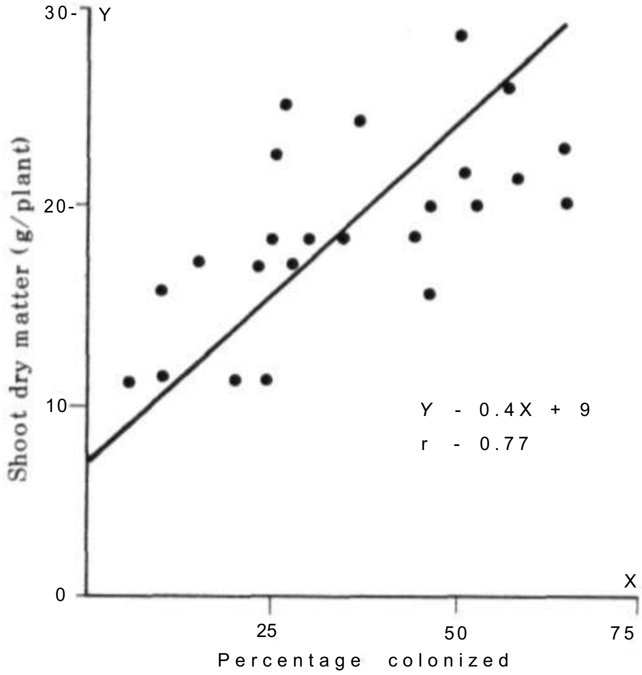
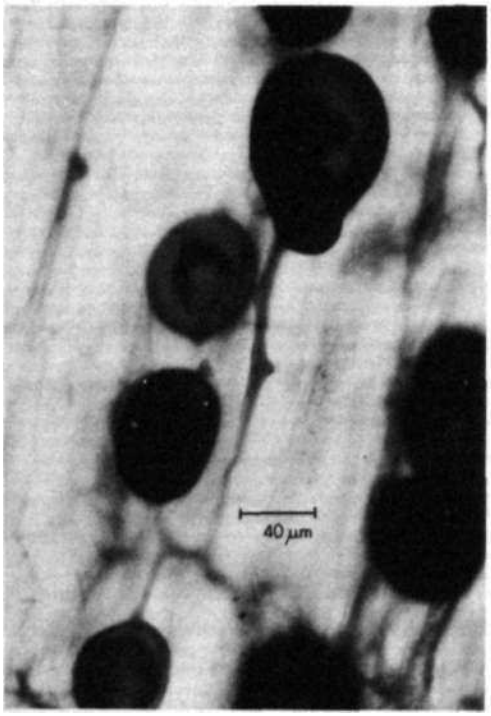


Figure 12. The relationship between the percentage of pearl millet cv BJ 104 colonized by mycorrhiza isolates and shoot dry-matter production.

a sterile Alfisol soil in a pot trial. Growth stimulation from VAM inoculation was of the same order as from adding superphosphate at 8 kg P/ ha, indicating that VAM fungi's presence can



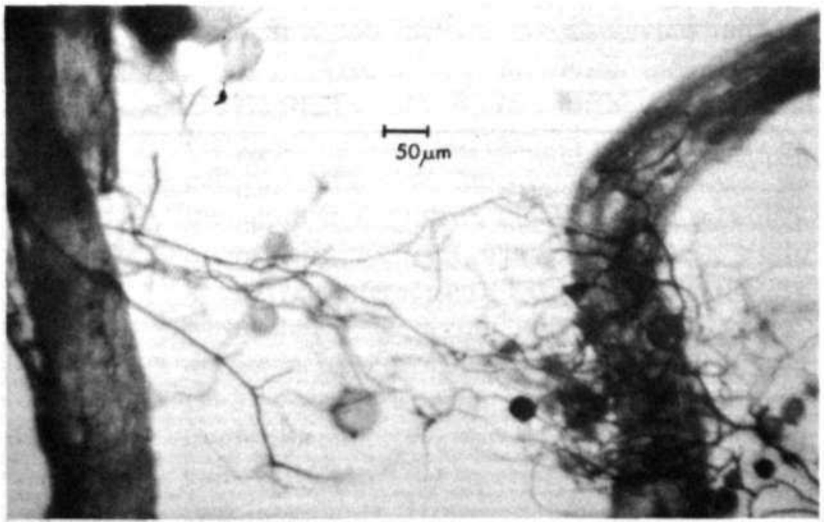


Figure 11. Our studies have shown that pearl millet forms mycorrhizal symbioses with VAM fungi. At left is a colonized root showing large vesicles formed by the fungus; above are two roots connected by VAM mycelia, showing the extramatrical chlamydospores of the fungus.

help provide plants with part of their P requirement.

We also examined the host plant genotype's role in developing the mycorrhizal association, by growing 50 pearl millet genotypes in the rainy season in an Alfisol field that received no P. In root samples taken 54 days after sowing, between 10 and 54% of the root was colonized by naturally occurring VAM fungi. The variation in infection between genotypes followed normal distribution with most, including the two widely grown cultivars BJ 104 and MBH 110, with 30 to 40% root colonization. Certain genotypes being more susceptible than others to colonization by VAM indicates scope for increasing mycorrhizal symbiosis by selecting and breeding. A pot-culture screen in nonsterile Alfisol with natural VAM flora showed that some hybrids had more mycorrhizal colonization than either of their parents, indicating that the extent of colonization can be influenced by the host genotype.

Plant Improvement

The plant improvement project has four objectives:

1. to identify, and incorporate into agronomically useful backgrounds, sources of new variability and/or traits of agronomic value;
2. to breed superior hybrids and varieties;
3. to develop improved procedures for breeding superior genetic material; and
4. to distribute improved germplasm and information to pearl millet scientists worldwide.

Endeavoring to meet those objectives, we have been evaluating parental material for biomass production and protein content; strengthening our hybrid project in male-sterile breeding; examining genotype x environment interactions to determine the optimum number, location, and type of tests needed in our program; clarifying physiological mechanisms that underlie good adaptation; and assembling nurseries with material showing good expression of various physiological-morphological traits and good disease resistance.

Source Material

In this project we have been concerned with both new variability and identifiable traits (morphological, physiological, biochemical, physicochemical, disease resistance, insect resistance) that could contribute to yield potential, yield stability, or grain quality. To incorporate new variability, we have made many crosses with material from the germplasm resources unit—approximately 4500 for breeders in Africa and 1000 for breeders in India.

The fewer crosses than in previous years reflect reduced labor resources and our concentrating on inbreeding and evaluating materials from previous years' crosses. The identified better inbred lines are placed in the Source Material Inbred Nursery (SMIN), which now contains 406 entries.

A study of biomass production in a range of cultivated and wild types identified many wild types and F3 lines from wild x cultivated crosses that accumulate dry matter faster than normal cultivated types. Before these can be used in the main breeding programs, further research will be necessary to determine whether the trait can be introgressed into the cultivated types without negative associations.

We continued to evaluate materials for the physiological-morphological nursery but fewer than previously. For earliness, 23 DBE lines and material from the pearl millet program at Kansas State University have been incorporated. Protein content evaluations also have been continued on several high and low lines, some of which have been incorporated. Further evaluation of these materials will be necessary in the 1983 rainy season.

Breeding

Output from pur breeding work encompasses pollinators (R-lines), male-sterile (A-) and maintainer (B-) lines, experimental varieties, and synthetics—together with promising progeny

ICRISAT millet breeders continued to draw from a wide variety of source material in wild and cultivated types to identify and utilize lines that could improve and stabilize yields with acceptable grain quality. Clock wise (from top left): millet PS 90 growing at Bambey, Senegal; variability in head length and girth in millet grown infields near Niamey. Niger; a high-tillering plant resulting from natural introgression from wild millet. Sadore, Niger; and Ankautess, a drought-resistant millet grown by a farmer near Sadore, Niger.

derived from the various projects. Work the past year is reported in each category.

Pollinator (R-line) development. The crossing program, given highest priority, has been vigorously continued. Several backcrossing projects to eliminate defects from existing elite lines have been initiated or continued with emphasis on large seed size, increased seed number per head, downy mildew resistance, smut resistance, ergot resistance, and rust resistance. Approximately 50 simple crosses among elite lines were made for pedigree selection, and 23 elite lines combined to constitute an R-Composite. More than 500 crosses were made among lines of good phenotype but with no hybrid performance record, with germplasm resource unit materials and with lines otherwise used as females (B-lines).

Selection of materials for testcrossing is carried out visually at the various stages of generation advance. More than 2000 test crosses were made this year, with existing male steriles used in approximately the following proportions: 5141 A, 45%; 5054A, 25%; 111 A, 10%; 81 A, 20%. Limited use of 111A and 81A reflects their late maturities compared with 5141A (ICRISAT Annual Report 1981, p.83, Table 17).

Yields of our best hybrids (prefix 1CMH) in the 1982 Elite Varieties Test (ELVT), which evaluates leading products, were 5 to 15% higher than those of the widely grown hybrid BJ 104 and the recently released variety, WC-C75. Table 20 presents pedigree details of our most advanced hybrids.

Table 20. Pedigree details for the most advanced ICRISAT pearl millet hybrids.

Hybrid (ICMH) No.	Breeding stream	Parents	
		Male	Female
423	Composite	EC-211	5141 A
418	Composite	BC-377	5141 A
415	Composite	WC-7209	5141 A
433	Pedigree	1CP206-44	5141 A
426	Pedigree	ICP220-10	5054 A
435	Pedigree	1CP226-50	5141 A

Male-sterile (A-line) and maintainer (B-line) development. Three male-sterile cytoplasms (A1, A2, and A3) have been recognized in pearl millet, but only A1 has been widely used in hybrid production, and then in only a few nuclear-cytoplasm associations. To help widen the genetic base, our crossing program with and among identified maintainers will be continued and strengthened in 1983.

Several projects have been initiated to select within an established or promising B-line or to introduce a desirable trait through backcrossing. Traits involved are sterility, ease of restoration, earliness, and resistances to downy mildew, smut, ergot, and rust. Conventional crossing projects have involved making all possible crosses among 10 established or promising maintainers, and deriving 349 A/B pairs from previously recognized B-lines.

We also have made and evaluated 2000 test crosses (largely with source material), and identified an additional 134 nonrestorers (92 on 81 A, 31 on 5141A, and 11 on new male-sterile lines derived from J 1623 x 3/4 ExB-96-1-10). They will be sib multiplied, evaluated for phenotypic acceptability as B lines, and then tested for combining ability before being converted into male-sterile lines.

Variety development. Approximately 30 experimental varieties (prefix ICMV) are constituted annually from various composites (Fig. 13). Before 1980 various selection procedures were applied to the different composites; since then six composites have been handled in a S2 testing scheme (2 years per cycle), one composite in a SI scheme (2 years per cycle), and 4 composites in a modified half-sib system (1-year cycle). Approximately 50 progenies are used in reconstituting each composite. The various composites and their characteristics are shown in Table 21.

In addition to the main project, dwarf versions of four of the above composites (WC, IVC, MC, SSC) and three additional composites (Early, Nigerian, Ex-Bornu) are being produced by introducing a dwarfing gene (d_2) by backcrossing. The conversion process has been virtually

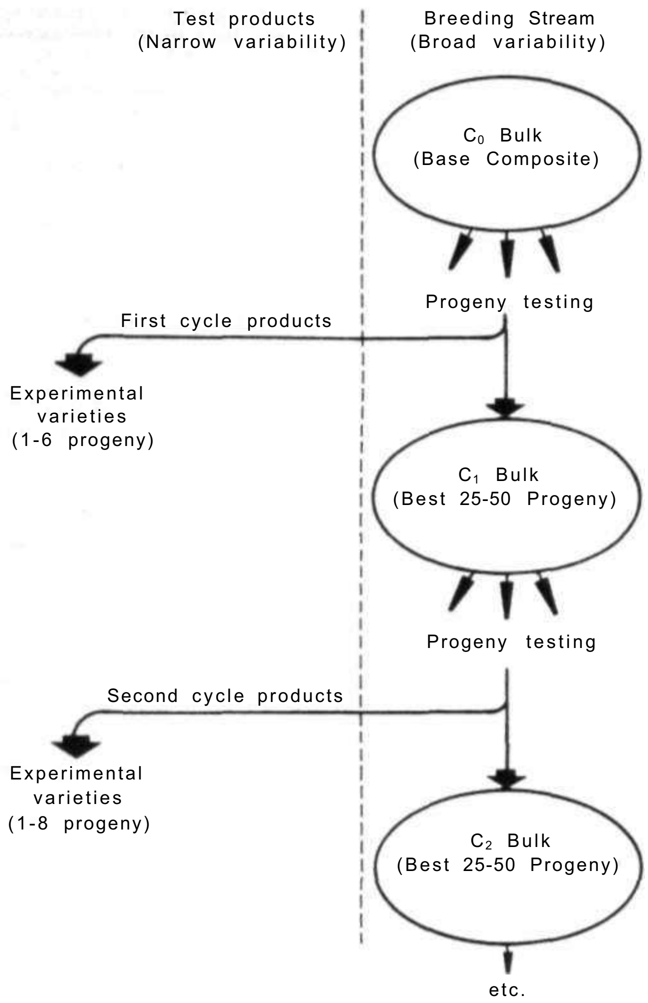


Figure 13. Generalized scheme for development of experimental varieties in pearl millet.

completed, and dwarf composite bulks, derived by combining d_2 dwarf F_4/F_5 progenies from the third backcross, have been compared with their tall (original) versions. Preliminary results from yield tests at ICRISAT Center and Bhavanisagar indicate that the d_2 dwarf versions yielded as much as their tall counterparts, and that Nigerian composite d_2 bulk yielded significantly more than its tall equivalent.

The performance of the most recent standard-height varieties from several composites seems to be improved little over varieties constituted at early selection cycles, so we are reevaluating both our procedures for constituting experimental varieties and the composition of the various composites. We may combine some of our current composites and reestablish a few new composites on the basis of elite varieties and inbreds. To help in the reevaluation, and to permit rapid appraisal of progress made in various composites, we have initiated a Bulk Composite Test, which will be grown every 2nd year after reconstituting the composites in which S_2 selection is practiced. Results in 1982 indicate that gains in yield have averaged between 2 and 4% per cycle in most composites (Table 21).

Synthetic development. Approximately 50 synthetics (prefix ICMS) are made each year from progeny generated by crossing existing lines, varieties, promising source material lines, and disease-resistant sources. Which progeny (generally F_5) to use in constituting a synthetic is usually determined on the basis of multilocation performance testing of the products of diallel mating (partial) of 10 to 20 parents in each of 5 diallels. Some source material progenies, however, are used after S_2 testing. Initial testing of synthetics is currently delayed until syn-2 seed is available (2 years after diallel testing).

Synthetics are tested in three stages—two Initial Synthetics Trials, an Advanced Synthetics Trial, then an Elite Varieties Test (ELVT),

ICRISAT's pearl millet synthetic ICMS 7703 has reached the final stage of prerelease testing in India. In 5 years of testing, it has given yields equal to the best hybrid's, shown low susceptibility to downy mildew, and given 20% more fodder,

Table 21. Charecteristics of various pearl millet composites undergoing recurrent selection, ICRISAT Centre, 1982.

Name	Date of initiation of testing	No. of cycles	Selection objectives	Gain per cycle (%)	Varities in advanced testing
Composites subjected to S_2 selection (from 1980)					
World composite (WC)	1974	5	Yield	2.6	C75,[a] P8004
Inter Varietal Composite (IVC)	1974	4	Yield	3.3	P77; P78, 5454, 98001
Medium Composite (MC)	1974	5	Yield	3,9	
Serere Composite-1 (SC-1)	1975	5	Yield	2.0	P 8001
New Elite Composite	1978	3	Yield	2.9	P 79
Composites subjected to S, selections					
Smut resistant Composite (SRC)	1980	1	Smut resistance; yield	-	
Composites subjected to HS selection (from 1980)					
Super Serere Composite (SSC)	1975	5	Bristles; yield	2.4	80164
New Early Composite (NEC)	1977	4	Yield	4.6	
D_1 Composite (D_1C)	1978	1	Yield	2.8	P7904
D_2 Composite (D_2C)	1980	2	Yield, height	7.4	

a. WC-C75 was released commercially in 1982.

which also includes hybrids and experimental varieties.

Synthetics in AICMIP tests in 1982 were: 4th year Advanced, ICMS 7703; 2nd year Advanced, ICMS-7704; 1st year Advanced, ICMS-7818, 7835; and Initial, ICMS 7857.

Procedures

An analysis of grain yields from stations cooperating in the AICMIP program has been undertaken to determine whether testing at ICRISAT Center under both high- and low-fertility conditions is warranted. Studies of the physiological mechanisms that underlie good adaptation and that could enable us to pinpoint reasons for genotype x environment interaction have been continued—concentrating on photoperiodic responses. They have shown that responses of varieties adapted to Indian conditions differ widely.

A selection study was initiated in 1980 to test two ways of selecting for increased grain numbers, previously shown (ICRISAT Annual Report 1978/79) to account for 50 to 75% of yield variation. From a genetically variable dwarf population of 1250 spaced plants (20 000/ha), 50 to 60 (from which selfed, S_1 seed was harvested) were selected for increased grain number by measuring the surface area of the main panicle, and another 50 to 60 by the number of productive tillers per plant.

For comparison we then selected a similar number purely on visual judgment of yield potential. Then we evaluated the three groups of S_1 progenies at normal plant populations (133 000/ha) the next year. The best 10 in each group (by yield and the original criteria) were identified (Table 22).

Reserve seed of each of the 10 were grown and used, after controlled pollination with mixed pollen, to produce three synthetics representing each selection criterion. The synthetics were compared in a 1982 yield test that included the original unselected population (Table 23).

Visual selection produced little change. Although selection for head numbers increased heads about 25%, the gain was completely offset by decreased head size and seed size. Selecting for head surface area, however, increased grain

Table 22. Grain numbers and grain yields for S, lines of pearl millet selected for head numbers, head surface area, and visual appearance, ICRISAT Center, 1982.

Selection criteria	N	Grain no./m^2 ('000)	Grain yield (g/m^2)	Head ($no./m^2$)	Head surface (cm^2)
Head numbers					
Selected S_1s	10	39.5	243	36	-
Population	60	33.4±3.88	195 ±22.2	29 ± 2.9	-
Head surface area					
Selected S_1s	10	39.5	274	.	222
Population	54	33.7 ± 3.43	209 ±19.9	-	192 ± 11.8
Visual appearance					
Selected S,s	10	40.8	256	-	-
Population	57	34.5 ± 4.31	210 + 22.5	-	-

number per head 25%, with no change in seed size. Head numbers declined slightly but the net result was a 15% yield increase, considerable gain for one cycle of selection. The synthetics will be compared again after further random mating, and head surface area as a selection criterion will be further tested on other populations.

Distribution

Thirty pearl millet scientists from all over India took part in field days at Hissar. ICRISAT Center, and Bhavanisagar. Most of them requested materials from our nurseries, and we provided more than 3000 samples. In addition to such specific requests, we assembled several nurseries of special material for distribution on request. Those nurseries include:

Parental materials
- Uniform Progeny Nursery

Advanced materials
- International Pearl Millet Adaptation Nursery
- International Pearl Millet Observation Nursery

Materials were also contributed to the various AICMIP trials as follows:

	Entries
Initial Hybrid Trial	1
Advanced Hybrid Trial	2
Initial Population Trial	3
Advanced Population Trial	7
Inbred Nursery	7
Resource Nursery	30

Table 23. Grain yield and yield components of experimental pearl millet varieties based on head surface area, head number, and visual appearance, ICRISAT Center, 1982.

Selection criteria	Grain yield (g/m^2)	Grain (no./ head)	Head ($no./m^2$)	Grain no./m^2 ('000)	1000 seed wt. (g)
Head surface area	267	2150	20.7	44.2	6.1
Head number	239	1560	27.7	43.3	5.5
Visual selection	225	1610	24.2	38.8	5.7
Original synthetic	230	1730	22.4	38.4	6.0
SE	±22.1	±85.9	±1.49	±3.30	±0.30

Looking Ahead

Physical stresses. We will begin 2 years of testing of selections made under high- and low-fertility conditions. Initial tests of synthetics made from early-generation selections from each environment indicated no difference in performance in higher-yielding environments (2-3 t/ha). Tests will now be on advanced lines in both low- and high-yielding environments.

We are ready to begin large-scale field screening for ability to emerge under crusted soils and declining soil moisture. Initial work will be on a selected set of germplasm lines to determine how much variability exists in millet for these characteristics. Beginning 1984, entries from all advanced breeding trials will be subjected to this screening as well.

Testing of selections for yield components other than grain number will continue from materials now in various stages of development. The use of head surface area as a selection criterion will be retested in other breeding materials.

Biotic stresses. Large-scale field screening for downy mildew, ergot, and smut at ICRISAT Center and for rust at Bhavanisagar will continue. Multilocational testing for resistance stability will continue with emphasis on evaluating factors that affect resistance stability and durability.

Efforts will be made to develop downy mildew resistance in commercially popular genotypes, based on information gathered with 7042. Development of ergot and smut resistant lines in more diverse backgrounds will continue, as will use of ergot and smut resistance in hybrids and synthetics in cooperation with breeders.

Screening for multiple disease resistance, initiated in 1982, to combine resistance to all the diseases will continue.

Nitrogen fixation. We will attempt to stabilize lines that stimulate high or low N_2-fixation in the Ex-Bornu population, and use them in crosses to analyze the heritability of this trait.

We will explore ^{15}N isotope-dilution technique's potential for screening lines of millet for ability to stimulate N_2-fixation. ^{15}N-enriched gas will be used to measure the N_2-fixation rate associated with millet seedlings and distribution of fixed nitrogen in the plant.

We will use field experiments to measure stability over seasons and sites of responses by millet to inoculation by N_2-fixing bacteria.

We also will collect VAM isolates from the traditional millet-growing areas of Rajasthan and Gujarat, and test the isolates' efficiency in promoting P uptake and plant growth under low fertility.

The interaction between P fertilizer type and amount added, and the response to VAM inoculation will be examined in nonsterile soil.

Multilocational trials will examine the influence of soil type and location on variation of root colonization by VAM among cultivars, and we will correlate colonization and P uptake in more detail. Advanced materials from breeders will be examined for the extent of VAM colonization.

Plant improvement. We will continue to emphasize development of elite inbreds, varieties, and synthetics. For the variety program, new composites using elite materials will be formed, and some of the existing composites showing little progress will be dropped. For hybrid breeding, the A-line project will be strengthened, and efforts will be increased to develop new disease resistant lines that can effectively compete with the widely used seed parent 5141A for earliness and general combining ability. We will endeavor to modify our approaches to ensure that data collection facilitates both the continued evaluation of the effectiveness of various breeding procedures adopted, and provides a basis for adopting new superior procedures.

Publications

Journal Articles

THAKUR, R.P., WILLIAMS, R.J:, and RAO, V.P. 1982. Development of ergot resistance in pearl millet. Phytopathology 72:406-408.

MICHELMORE, R.W., PAWAR, M.N., and WILLIAMS, R.J. 1982. Heterothallism in *Sclerospora graminicola.* Phytopathology 82:1368-1372.

Conference Papers

ALAGARSWAMY, G., and BIDINGER, F.R. 1982. Nitrogen uptake and utilization by pearl millet *Pennisetum americanum* (L.) Leeke. *In* Plant Nutrition 1982: Proceedings of the Ninth International Plant Nutrition Colloquium, 22-27 Aug 1982, Warwick University, England: Commonwealth Agricultural Bureaux.

ANDREWS, D.J., RAI, K.N., and PHERU SINGH. 1982. Recurrent selection in pearl millet populations. Presented at the All India Coordinated Millet Improvement Project Annual Workshop, 26-28 Apr 1982, Tamil Nadu Agricultural University, Coimbatore, India.

DART, P.J., and WANI, S.P. 1982. Non-symbiotic nitrogen fixation and soil fertility. Pages 3-27 *in* Non-symbiotic nitrogen fixation and organic matter in the tropics. Transactions of the 12th International Congress of Soil Science, vol. 2,8-16 Feb 1982, New Delhi, India.

WANI, S.P. 1982. Nitrogen fixation associated with sorghum and millet. Presented at the Second Annual Workshop of Coordinated Project on Biological Nitrogen Fixation, 19-21 Aug 1982, New Delhi, India.

WANI, S.P., DART, P.J., and UPADHYAYA, M.N. 1982. Factors affecting nitrogenase activity (C_2H_4 reduction) associated with sorghum and millet estimated using the soil core assay. Presented at the Second International Symposium on N Fixation with Non-legumes, 5-10 Sept 1982, Banff, Canada.

WILLIAMS, R.J., SINGH, S.D., and THAKUR, R.P. 1982. Sources of disease resistance in pearl millet. Presented at AICMIP Workshop, 26-28 Apr 1982, Tamil Nadu Agicultural University, Coimbatore, India.

Miscellaneous

ANDREWS, D.J., and ANAND KUMAR, K. 1982. Induction of downy mildew resistance in pearl millet male-sterile Tift 23d2. Mutation Breeding Newsletter 20:1-3.

RAI, K.N., ANDREWS, D.J..and BABU, P.P. 1982. Hybrid potential of ms 81 A — A new male-sterile line of pearl millet. MILWA1 Newsletter 1:2.

WILLIAMS, R.J., PAWAR, M.N.. and SINGH, S.D. 1982. The enigma of BJ-104—an explanation. IWGGDM Newsletter 3(1):3.

WILLIAMS, R.J.. SINGH. S.D., and PAWAR, M.N. 1982. Methodology of parent selection for inheritance of resistance studies. IWGGDM Newsletter 4(2):2-3.

CHICKPEA

Contents

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CHICKPEA

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

During the 1981/82 cropping season our activities continued at three main locations: (1) ICRISAT Center at Patancheru (18°N, 78°E), concentrating on short-duration desi types; (2) Hissar (29°N, 75°E), in cooperation with Haryana Agricultural University, for long-duration desi and kabuli cultivars; and (3) ICARDA, our sister institute at Aleppo, Syria (36°N, 37°E) for kabuli types for winter or spring sowing in the Mediterranean region and South and Central America.

We continued to use subsidiary centers at Gwalior (26° N, 78° E) in central India for testing, at Tapperwaripora (34°N, 75°E) in Kashmir, and at Terbol (34° N, 36° E) in Lebanon, for off-season advancement. We acknowledge contributions of many cooperators in India, through the All-India Coordinated Pulses Improvement Project (AICPIP) and elsewhere, who grew trials and materials distributed from the main centers.

The season was unfavorable for chickpeas. In south and central India, rains continued into November; at Patancheru the total annual amount was nearly 1200 mm, 50% higher than normal. The rains hampered seedbed preparation at ICRISAT Center and led to poor plant emergence. One week of continuous rain following the early (mid-September) sowing caused seed rotting so emergence was near zero. Poor stands were further reduced by collar rot and fusarium wilt, making interpretation of data difficult.

In the northern areas of the Indian subcontinent, rain in October-November encouraged sowing larger than normal areas but excessive

Both desi- (smaller seeds at left) and kabuli-type (larger, whiter seeds at right) chickpeas continued to be the focus of research in ICRISAT's chickpea improvement program, with emphasis on improved cultivars and genetic stocks that can give higher and more stable yields in varying cropping situations.

rains during the growing season favored ascochyta blight and botrytis gray mold, which caused losses of up to 50% in Punjab, India, and in Pakistan. At Hissar and most other centers in northern India few genotypes survived, so analyzable data were few.

Heliothis damage was normal except for severe infestations in central India.

In the Mediterranean region winter temperatures were unusually low with March and April dry, followed by unseasonally wet May and June. In Syria the chickpea area was much larger than normal but growth of the winter-sown crop was severely depressed by the cool, dry conditions and many genotypes previously considered relatively cold tolerant were badly damaged. The continuing wet conditions favored development of ascochyta blight in both winter- and spring-sown chickpea and many farmers plowed their damaged crop under and replaced it with melons. At Tel Hadya, pod damage was more severe than normal and previously resistant lines showed severe symptoms. Leaf miner damage was widespread but *Heliothis* populations were lower than normal.

Diseases

Surveys

We conducted surveys in Chile, Mexico, USA, Pakistan, and parts of India. In Chile, wilt *(Fusarium oxysporum* f .sp. *ciceri),* dry root rot *(Rhizoctonia bataticola),* and black root rot *(Fusarium solani)* were important diseases. In Mexico, wilt was widespread and serious, and black root rot, collar rot *(Sclerotium rolfsii),* rust (*Uromyces ciceris-arietini),* and iron chlorosis were common. In USA, wilt and iron chlorosis were common in chickpea trials at Yuma, Arizona. In Pakistan, ascochyta blight *(Ascochyta rabiei)* was the most widespread and serious disease, causing extensive and severe chickpea damage. Root rot *(Rhizoctonia solani)* was another important disease in Pakistani farmers' fields, and iron chlorosis, stunt (pea leaf-roll virus), and wilt were common in experiment station crops. Excessive rains throughout the latter half of the season in northern India led to serious, extensive damage from ascochyta blight and botrytis gray mold *(Botrytis cinerea).* Other diseases commonly observed were alternaria blight *(Alternaria alternata),* wilt, stunt, and stem rot *(Sclerotium sclerotiorum).*

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

Screening for resistance. Of more than 1200 new germplasm accessions screened in wilt-sick plots, 73 had less than 20% of the plants killed. We now have screened all chickpea germplasm accessions available in our Genetic Resources Unit for resistance to fusarium wilt. The 72 germplasm selections with less than 20% mortality due to wilt last season (1980/81), screened again in 1981/82, revealed 25 resistant (less than 10% mortality). Only three (ICC-933, -1987, and -3072) of the 18 lines selected from germplasm in 1979/80 remained resistant under repeated screening.

Of the 72 lines with less than 10% stunt infection, only ICCC-10 resisted wilt; of 5 germplasm selections that resisted pod borers last season, only ICCC-1403 resisted wilt this year. Mortality was less than 20% in 9 of 49 new pod borer-resistant germplasm selections we screened in the wilt-sick plot. None of the 22 ascochyta blight resistant lines screened were resistant to wilt.

Breeding for resistance. We made 79 crosses involving wilt- and root rot resistant parents; 31 involved short-duration genotypes and sources resistant to Race 1 of *Fusarium oxysporum* for peninsular India; 32 involved long-duration desi genotypes and sources of resistance to Races 1 and 2 for northern and central India; 14 involved kabuli and wilt-resistant kabuli types. Eight backcrosses of wilt-resistant parents were attempted with high yielding cultivars of desi and kabuli types.

F_1 generations of nine crosses made earlier were advanced in off-season and in main-season nurseries and 15 F_2 and F_3 bulks, and 1762 F_4

and more advanced progenies and bulks were screened in the wilt-sick plot at ICRISAT Center. We selected 1469 single plants and 282 bulks for further evaluation in 1982/83. In addition, we evaluated (at ICRISAT Center) 470 desi and 33 kabuli lines previously selected for wilt resistance. The best desi types will be tested in replicated trials next season. Several wilt-resistant lines in replicated tests gave yields similar to Annigeri's, the best control; eight of them are being included in international nurseries in 1982/83. Additional kabuli types with acceptable seed type and larger seed size were developed.

At Hissar, we screened, in a wilt-sick plot, 56 F_3 populations, 838 F_4 and more advanced progenies and bulks, along with 614 desi and 17 kabuli lines, selected previously for wilt resistance. As with the other materials, most of the lines were destroyed by ascochyta. We selected only a few single plants for further testing.

Inheritance studies. Evidence has been obtained that resistance to Race 1 of fusarium wilt is governed by two independent recessive genes that separately delay wilting but must be present together for complete resistance.

Resistance to Race 2 appears to be controlled by two other recessive genes.

Biology and epidemiology. Continuing studies of *F. oxysporum* f.sp. *ciceri* survival, we buried infected roots with 5 cm of the stem base (stubble) from wilted chickpea plants in soil in pots in March 1978. Four pieces of stubble were carefully removed from the pots every 3 months in attempts to isolate the fungus. The stubble had fully decomposed after 33 months. Last year (1980/81) we detected the fungus up to 39 months by planting seeds collected from healthy plants of JG-62, a wilt-susceptible cultivar, in the same pots. This year, we detected the fungus after 51 months. The experiment is continuing.

In another experiment where we tested burial depths of infected roots, the fungus has survived 36 months in infected roots buried 60 cm deep.

Influence of crop rotation and intercropping. In June 1980, in collaboration with our agronomists, we initiated a 4-year experiment to study the influence of crop rotation and intercropping on wilt in a wilt-sick plot. The second year's results were similar to those of the first year: no treatment influenced wilt incidence in the susceptible cultivar, JG-62, which showed nearly 100% incidence. The experiment is continuing.

Eradication of the fungus from seed. Last year, we reported that seed, dressed with Benlate-T® (30% benomyl + 30% thiram) at 2.5 g/kg seed, remained free of the fungus when sown 1 year later. This year we established that seed dressing with the same formulation effectively eradicated the fungus from dry seed up to 22 months after seed treatment, so international exchange of seed that is free from *F. oxysporum* f.sp. *ciceri* is possible.

Multiple Soilborne Disease Screening

Fungi in the multiple disease-sick plot at ICRISAT Center, in order of prevalence, are *F. oxysporum* f.sp. *ciceri, Rhizoctonia bataticola, Sclerotium rolfsii, R. solani,* and a sterile seedling-rotting fungus.

This year, we retested 195 lines that showed less than 20% mortality in 1979/80 in the multiple disease-sick plot; 42 of them showed less than 10% mortality. Of the 63 lines that showed multiple resistance in 1980/81, 46 maintained resistance this year. Four lines with multiple resistance were selected for the 1982/83 International Chickpea Root Rots/Wilt Nursery. We confirmed the multiple resistance of an ascochyta blight resistant germplasm accession, ICC-3935, and eight of the nine kabuli chickpea germplasm accessions resisted wilt in this year's tests. We also tested 46 kabuli chickpea lines developed by breeders at ICRISAT Center for multiple resistance, and identified 17 lines with less than 20% mortality.

To monitor root pathogens during the chickpea season, we periodically isolate fungi from wilted/dried plants collected from the multiple disease-sick plot. The results (Table 1) showed that *F. oxysporum* f.sp. *ciceri* dominated

Table 1. Periodic isolations(%) from wilted/dried plants of chickpea collected from multiple disease sick plot, ICRISAT Center, 1981/82.

Date collected[1]	*F. oxysporum* f. sp. *ciceri*	*R. bataticola*	*S. rolfsii*	*F. solani*	*R. solani*	Others
13 Nov	23	20	42	11	2	
7 Dec	42	26	21	3	3	
28 Dec	40	28	16	10	2	
18 Jan	43	30	3	12	7	2 (white root
5 Feb	42	40		11	2	rot fungus)
26 Feb	45	46				

1. Date sowed: 16 Oct 1981.

throughout the season followed by *R. bataticola,* which was more prominent from February as ambient temperatures rose (more than 30°C). *S. rolfsii,* which was responsible for about half of the seedling mortality, caused no mortality after January. *F. solani and R. solani* caused mortality only to mid-February; *R. solani* was the least common fungus in the multiple disease-sick plot.

Dry Root Rot (*Rhizoctonia baiaticola*)

Two crosses were made to transfer root-rot resistance to Annigeri, and their F,s were advanced in the off-season nursery in Kashmir.

Ascochyta Blight (*Ascochyta rabiei*)

Our laboratory tests confirmed that dressing seed with a 0.3% formulation of Calixin M® tridemorph + 30% maneb) eradicates the fungus, such dressing should prevent moving the fungus on seed from one location to another. Exposing the seed to sun from 0830 to 1700 hr for 20 days in May did not control seedling infection.

Breeding for resistance. We made *26* crosses between 3 ascochyta-resistant lines (that ICARDA identified) ILC-72, -202, and -3279, and northern Indian desi and kabuli cultivars. We also made 74 crosses involving northern Indian material that had shown resistance last season to ascochyta and/or botrytis in north India.

F_2 populations of ascochyta-resistant desi types previously crossed onto BG-209, Pant G-114, and L-550 were screened for ascochyta resistance at ICARDA, at NARC in Pakistan, and at PAU, Gurdaspur, and Palampur in Punjab and Himachal Pradesh, India. No plants maintained resistance in the severe epidemics at ICARDA and in Pakistan, but resistant plants were selected at Gurdaspur and Palampur and their progenies will be tested further in 1982/83.

Stunt (Pea Leaf-roll Virus)

Work on screening for resistance to stunt was continued at Hissar. Alfalfa (to augment disease pressure) was planted around the nursery (0.5 ha) 1 September 1981 with chickpea planted 4 October. The stunt-susceptible cultivar, WR-315, was planted after every five test rows as an indicator-cum-spreader. Average stunt incidence in WR-315 was 30%, which indicates that the previously used mixture of hosts of the virus and vector(s) is better than a single crop of alfalfa.

Some accessions with less than 10% infection in the last two to five seasons showed similarly good reactions during 1981/82. Accession ICC-2385 has had less than 10% infection for the sixth consecutive season, and accession ICC-2546 gave similar results for the fourth consecutive season. We tested 125 ascochyta blight-resistant accessions this year, but only one, ICC-3I27, showed any resistance to stunt.

Breeding for resistance. Fifteen crosses were made involving Pant G-114, BG-209, and L-550 with 5 lines: ICC-2385, -3718, -6433, -6934, and -10495, which have shown consistently low stunt infection.

When we screened our F_2 populations of 8 crosses we made between stunt-resistant Collection 327 and adapted desi and kabuli lines, infection rates ranged from 28.1 to 52.1%, and we selected 155 plants for retesting next year. Additionally, we tested 3 F_3 and 9 F_4 bulks and selected 90 plants from the F_3 and 158 from the F_4 bulks. Of 14 screened F_4 progenies from a cross, P-4353 x WR-315, only 1 showed less than 10% infection.

Mosaics

We continued studies to identify and characterize cucumber mosaic virus (CMV) and bean yellow mosaic virus(BYMV). *Aphis craccivora* and *Myzus persicae* transmit both viruses, but not persistently. Purification procedures were standardized for both viruses. CMV particles were isometric and were 28 to 30 nm diameter while those of BYMV were flexuous, rod-shaped, and 750 nm long and 15 nm wide. Both viruses were identified by specific antisera in agar double-diffusion tests. CMV was identified also by enzyme-linked immunosorbent assay (ELISA). An antiserum for CMV of 1:1024 titer was produced. Physicochemical properties of CMV also were determined.

We screened, through sap inoculation, 143 germplasm accessions for resistance to CMV; two (ICC-1781 and -8203) remained free from infection. For BYMV, we screened 106 germplasm accessions, and 9 remained free from infection.

Botrytis Gray Mold (*Botrytis cinerea*)

With the help *of* scientists *of* G.B. Pant University of Agriculture and Technology at Pantnagar, India, we screened 1984 new germplasm accessions for resistance to this disease, and confirmed resistance in ICC-1069 and -6250 and tolerance in ICC-7574. And we found 9 new accessions resistant, which we shall retest next year. A procedure to screen chickpea material for resistance in an isolation-plant propagator was standardized. We identified 16 accessions with moderate resistance (5 rating on 1 to 9 scale).

None of the eight seed-dressing fungicides tested, alone or in combination, eradicated the seedborne fungus, nor did solar heat treatment.

Breeding for resistance. We made 60 crosses between the best sources of botrytis resistance and northern Indian desi and kabuli cultivars, and advanced F_1 and F_2 populations of earlier crosses for screening in 1982/83 at Pantnagar.

Alternaria Blight (*Alternaria alternata*)

We studied the symptoms in detail, and identified the causal fungus as *A. alternata.*

Insect Pests

Surveys

Our surveys of pest damage on chickpea in farmers' fields this year covered four states of India—Orissa, Uttar Pradesh, Bihar, and West Bengal. The average percentage of pod damage was 5.1, slightly lower than the 7.8% average recorded from 647 farmers' fields since 1977. *Heliothis* damage was also particularly severe in Madhya Pradesh, and many farmers dusted their chickpeas with BHC, attempting to control that pest.

Almost all pod damage on chickpea was caused by *Heliothis armigera,* but in some areas other pod borers, including *Autographa nigristriga* and *Diachrysia orichalcea,* were somewhat important. In addition to pod damage, *Heliothis* can cause considerable vegetative and floral damage, which we could not quantify because

ICRISAT scientists survey farmers' fields to assess damage by pests and findings are used to design preventive measures. Four states of India—Bihar, Orissa, Uttar Pradesh, and West Bengal—were surveyed this year.

most of our surveys are when pods are maturing. Cutworms seriously damaged this crop at the seedling stage in some areas; termites also killed some plants. In general, chickpea is attacked much less by insect pests than is pigeonpea, but in some areas and in some years *Heliothis* can damage up to 100% of chickpea pods.

At ICRISAT Center the *Heliothis* populations on chickpeas at the vegetative and podding stages were greater this year than last year. More than 50% of susceptible cultivars' pods were damaged where no pesticide was used. Other insect pests were of little or no importance but rats damaged some fields.

All our trials at Hissar, where we screen for resistance to *Heliothis* in late-maturing and kabuli materials, were destroyed by ascochyta blight. In the few plots where pods set before the blight killed the plants, more than 50% of the pods were destroyed by *Heliothis.*

Monitoring *Heliothis* Populations

As described in the pigeonpea section of this report, we supplement our counts of eggs and larvae of *Heliothis* on the crops with counts of moths in light and pheromone traps at ICRISAT Center and at several other locations in India, in cooperation with entomologists of the All India Coordinated Pulse Improvement Project. Figure 1 shows data on male *Heliothis* moths caught in pheromone traps set in pesticide-free chickpea fields at ICRISAT Center together with counts of larvae on that crop. We found a few larvae on plants in October soon after sowing, large catches in the pheromone traps in late November, and a peak infestation of larvae in December. We plan to investigate the relationship between light and pheromone traps with counts of the pest on its host crops in more detail next year.

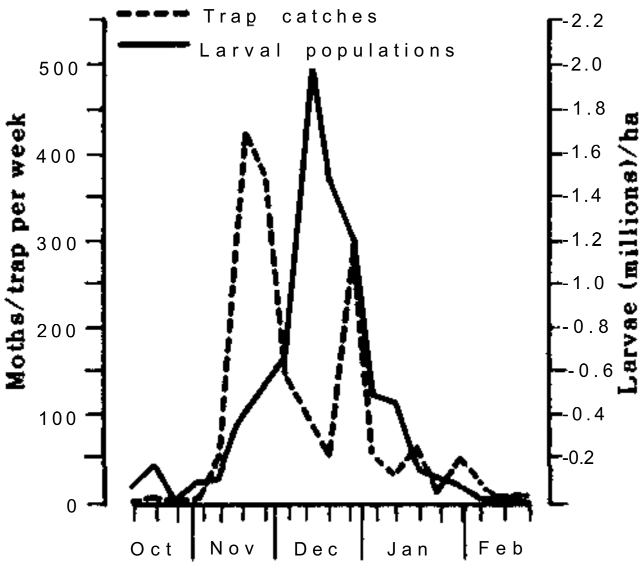


Figure 1. Average catches of male *H. argmigera* moths in pheromone traps and counts of larvae in surrounding chickpea fields in the pesticide-free area of ICRISAT Center, 1981/82.

Resistance to *Heliothis*

Screening for resistance. In previous reports we recorded progress in screening germplasm of more than 12000 accessions for resistance to *Heliothis* and our success in selecting some genotypes that have reduced susceptibility to this pest. One of the least susceptible accessions, ICC-506, an early-maturing desi type, entered in a number of trials this year, again had a relatively low percentage of pods damaged by *Heliothis.* ICC-506 also recorded high yields when it grew on wilt-free soils.

Although we have had most success in our search for resistance to *Heliothis* in the early-maturing germplasm, we have also found appreciable differences in susceptibility in the mid-maturity group. Data from one of our trials of mid-maturity selections are summarized in Table 2. All the selections were considerably less susceptible to *Heliothis* damage than ICC-3137, the susceptible check. But no selection gave a substantial improvement, either in resistance or yield, over K-850, the commonly used mid-maturity check.

Mechanisms of resistance. Biochemists of the Max-Planck Institute in Munich collaborated with us in an attempt to determine the mechanisms of resistance by studying biochemical differences between our selections that are resistant and those that are susceptible to *Heliothis* attacks. Our collaborative study has shown what appears to be a fairly strong correlation between the malic acid content of the plants' exudates and resistance. Exudates of our most resistant cultivars have the highest malic acid contents. In our collection of exudates from a range of more- and less-susceptible cultivars grown at ICRISAT Center and at Hissar, we found very little exudate on plants at Hissar, and the small amount collected from there had little malic acid. The lack of malic acid there may be associated with the ascochyta blight epidemic, or the environment at Hissar may not be conducive to exudation. If so, materials selected for resistance at ICRISAT Center, which may owe their resistance to a concentrated acid exudate, might not have resistance at Hissar or at locations with a similar environment. That could explain why some ICRISAT selections have proved disap-

Table 2. Pod damage caused by *Heliothis armigera* and yields from mid-maturity chickpeas (selected earlier for resistance to this pest) in a pesticide-free, balanced lattice square design trial, ICRISAT Center, 1981/82.

Chickpea line	Mean pod damage (%)	Yield (kg/ha)
ICCL-79037	11.2	1350
ICC-11088	16.0	1220
ICC-9966	12.2	1140
ICC-10224	15.9	950
ICCL-80130	14.1	1310
ICCL-78001	11.7	1580
ICC-2812	11.7	1330
K-850 (check)	13.8	1420
ICC-3137 (susceptible check)	30.5	690
SE	±1.36	±43
CV(%)	17.9	7.1

pointing when grown by collaborators in northern India.

Breeding for resistance. Increased attention was given to breeding for resistance to *Heliothis,* including incorporating resistance into adapted backgrounds, recombining different resistance sources, and transferring fusarium-wilt resistance to *Heliothis-Tesistant* lines, most of which appear to be highly susceptible to fusarium wilt.

To investigate their inheritance and to recombine different sources of resistance, we crossed six short- and six medium- and long-duration, resistant, and susceptible genotypes in diallel combinations. We also made 27 desi and 12 kabuli crosses of resistant and adapted lines and 8 crosses to transfer wilt resistance into *Heliothis-resistant* materials.

F_1 diallel trials of desi (6 x 6) and kabuli (4 x 4) resistant lines were conducted at ICRISAT Center under pesticide-free conditions. The results of the desi trial indicated that variation in pod borer damage is predominantly additive (Table 3). ICC-5800-EB's pods were damaged more than pods of other parents, which was reflected in highly significant positive general-combining-ability (gca) effects. The data indicate that the conventional breeding methods we are using will be effective in handling resistance to *Heliothis.* In the kabuli trial, borer damage was higher than expected on the parental lines, variation was less, and gca and specific-combining-ability (sea) effects were not significant.

Forty F_2 bulks, and 811 F_3 and 121 F_4 progenies were grown under unsprayed conditions at ICRISAT Center, and single plants were selected to be evaluated in progeny rows next year.

The comparisons of breeders' materials (selected under insecticide protection) with lines resistant to *Heliothis* were repeated at ICRISAT Center (short and medium duration) and Hissar (long duration) under protected and nonprotected conditions.

At ICRISAT Center, yields from the insecticide-protected trials were significantly higher than those from the trials that received no protection (Table 4). In the short-duration group, fusarium wilt killed the resistant lines ICC-506-EB, IC-738-8-01-1P-BP-EB, and 7394-

Table 3. Estimates of general (gca) and specific combining ability (sea) variances, and gca effects in an F_1 diallel of *Heliothis* resistant chickpea types, ICRISAT Center, 1981/82.

		Variances		
Source	d.f.	Days to flower	Borer damage	Plant yield
gca	5	28.62**	6.01**	0.72**
sca	15	6.68*	0	0
Error	40	9.18	9.20	2.67
		gca effects		
Parents		Days to flower	Borer damage	Plant yield
ICC-3474-EB		2.80**	-1.76	1.15*
ICC-5800-EB		-3.45**	5.25**	-0.99
ICC-10619-EB		-5.32**	-0.74	-0.22
IC-738-8-1-1P-BP-EB		-5.71**	0.26	0.01
IC-7320-11-2-1H-B-EB		5.99**	-1.66	-1.13*
IC-73213-9-1-3H-B-EB		5.68**	-1.34	-1.18*
SE(gi)[1]		±0.98	±0.98	±0.52

1. Standard error of difference between two gca effects.

Table 4. Seed yields (kg/ha) of *Heliothis-resistant* and breeders' chickpea lines in insecticide-free and protected trials, ICRISAT Center, 1981/82.

	Short-duration cultivars		Medium-duration cultivars	
	Unprotected	Protected	Unprotected	Protected
Heliothis-resistant lines	810	1190	650	990
Breeders' lines	750	1060	620	1060
Annigeri	610	1310	630	1170
SE	±78		±55	
Mean	740	1120	640	1040
SE	±43		±35	

18-2-1P-BP-EB and they were omitted from the analysis. There were no significant yield differences among short-duration cultivars but there were significant differences in the medium-duration group, primarily from differences within breeders' materials and the *Heliothis*-resistant lines. Both groups showed significant interactions between entries and insecticide protection, but that resulted mainly from the comparison of Annigeri with the remaining entries. Unlike last year, there was no indication that breeders' materials were lower yielding than resistant lines without protection, nor that breeders' materials responded more to insecticide.

At Hissar the trials were damaged by ascochyta blight, and yield data were not recorded.

Plant Density and Pesticide

We previously found that increased plant populations lead to increased populations of *Heliothis* larvae per unit area. This year, we compared ICC-506, one of our most resistant selections, with Annigeri, a well known, highly productive but susceptible cultivar, at three spacings, in a pesticide-free field. The susceptible cultivar had large increases in eggs and larvae and pod-damage percentage at the closer spacings (Table 5). Spacing had comparatively little effect on the same factors in ICC-506. Although yields were not greatly affected by spacing, the lowest plant populations produced the lowest yields. ICC-506 had less *Heliothis* infestation, less pod damage, and higher yields than Annigeri, which indicate that ICC-506 at 167 000 plants per hectare (56 kg/ha seed) performed satisfactorily in the pesticide-free area when *Heliothis* populations were higher than average.

Natural Control

Heliothis has relatively few natural enemies on chickpea, probably because the acid exudate discourages most fauna. The commonest parasite this year was *Campoletis chlorideae,* a small wasp that attacked the young *Heliothis* larvae, particularly during the vegetative stage of the crop (October to December). The only other parasite recorded in substantial numbers on chickpea this year was the tachinid fly *Carcelia illota,* which emerged from larger *Heliothis* larvae.

Samples of larvae collected from the spacing trial indicated less parasitism on ICC-506, the resistant selection, than on Annigeri, and less on the closer spaced plants of both cultivars. But overall parasitism (<4%) was very low in the *Heliothis* larvae collected from this trial. We need further study of the effects on parasitism of spacing and cultivars.

Insecticide Use

Fusarium wilt masked results of our trial to compare effects of insecticide (2 sprays of endosulfan at 0.7 kg a.i./ha) on ICC-506 and

Table 5. Effects of plant density on *Heliothis armigera* populations, pod damage, and yields of chickpea cultivars, resistant and susceptible to the pest, ICRISAT Center, 1981/82.

Cultivar	Spacing (plants/m^2)	*Heliothis*/m^2 Eggs	Larvae	Pod damage (%)	Seed yield (kg/ha)
ICC-506	8.3	40	21	11	1060
(resistant)	14.7	40	35	11	1400
	33.3	54	31	13	1320
Mean		45	29	12	1260
Annigeri	8.3	36	49	38	840
(susceptible)	14.7	60	69	46	850
	33.3	104	101	58	870
Mean		67	73	47	850
SE (m) cultivars		±1.9	±0.8	±1.2	±33
Overall	8.3	38	35	25	950
	14.7	50	52	28	1130
	33.3	79	60	36	1090
SE (m) spacings		±3.8	±2.5	±2.5	±32
SE of means of cultivars within spacings		±4.8	±3.0	±3.2	±49
SE of means of spacings within cultivars		±5.4	±3.5	±3.6	±45

Annigeri. Although *Heliothis* caused considerably less pod damage on unsprayed plots of ICC-506 (7.1%) than on Annigeri (14.9%), ICC-506 yielded less, presumably because it is more susceptible to wilt. Mean yield from protected plots (1442 kg/ha) was only 12% more than from unprotected plots. Annigeri's response to pesticide was a yield increase of 14%; ICC-506's was 10%.

Physiology

Irrigation

Nonirrigated chickpeas are progressively stressed as soil moisture recedes and the evaporative demand of the atmosphere increases. Under those conditions irrigation gives large yield increases (ICRISAT Annual Report 1981, pp. 102-103).

Using cv Annigeri, a cultivar well adapted to peninsular Indian conditions, we studied responses to irrigation at different stages of growth at ICRISAT Center. Irrigation increased both dry matter and seed yield (Table 6), except for a single irrigation during the pod filling stage, which was probably too late to be effective. Two irrigations applied during the vegetative and pod filling stages nearly doubled yields. Two irrigations, one during the vegetative stage and the other at flowering gave no yield advantage over a single irrigation applied during the vegetative stage.

Drought Tolerance

We developed a screening technique of growing chickpea cultivars under both drought stress and well-irrigated conditions on an Alfisol of low water-holding capacity. A major factor influencing yield under drought conditions is growth

Table 6. Response to irrigation in chickpea (cv Annigeri) on a deep Vertisol, ICRISAT Center, 1981/82.

Stage irrigation applied	Total dry matter (kg/ha)	Seed yield (kg/ha)	Harvest index (%)
No irrigation	2170	1250	57
Vegetative (31 days)	3240	1770	55
Flowering (52 days)	2940	1660	56
Podfill (73 days)	2270	1300	57
Vegetative + flowering	3580	1720	48
Vegetative + podfill	3970	2280	57
Vegetative + flowering + podfill	4070	1740	43
SE	±124	±106	±2.3
CV (%)	11.7	19.1	13.1

duration: the earlier the cultivar, the more it tends to escape the drought. But under drought stress, differences exist among cultivars of similar growth duration. The differences under drought reflect differences in both intrinsic yielding ability (measured by yields under well-irrigated conditions) and drought tolerance. To obtain a quantitative measure of drought tolerance, we use a multiple regression analysis that accounts for both the effects of growth duration and yield potential (ICRISAT Annual Report 1979/80, p.83); Annigeri was one of the most drought tolerant cultivars thus identified over 3 years of testing.

Last year we screened more than 480 chickpea lines; this year, 430 more. Seven of the lines that appeared most drought tolerant last year were tested again this year in a replicated trial that included Annigeri. None was as drought tolerant as Annigeri, and none yielded as well under moisture stress. In future work, Annigeri will be the drought-tolerant standard others are judged by.

Plant Density

At ICRISAT Center, optimum growth duration of unirrigated chickpeas is usually between 85 and 90 days. Earlier- or later-maturing cultivars yield less.

We investigated in a field trial whether yields of very early cultivars could be increased by growing them in high population densities. Maturities of the eight cultivars we compared ranged from 70 to 100 days. We used the normal 33 plants/m^2, and populations twice and three times as high. Yields at the higher populations did not differ statistically and there were no significant interactions between cultivars and plant density. Apparently crowding cultivars produces no yield advantage. Again, we confirmed that cultivars of around 85 days' duration produce the highest yields.

Flower and Pod Development

In chickpea, pods may fail to develop from reproductive buds for two reasons: the buds may give rise to small shriveled pseudoflowers instead of developing into flowers (Fig.2), or normal flowers may develop but fail to set pods. This year we investigated the effects of several environmental factors on both pseudoflowcr production and flower abortion.

Shading. At ICRISAT Center, we erected vertical screens running east-west in the field, with rows of chickpeas at right angles to the screens. The plants nearest the screens on the northern side were shaded most of the day; those farthest away were not shaded at all. Observations made on five cultivars in the shaded area, in the unshaded area, and in the partially shaded area revealed that shading significantly increased

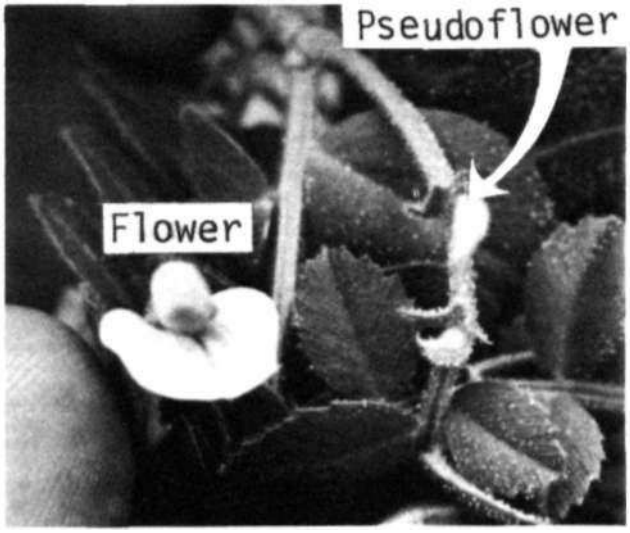


Figure 2. ICRISAT scientists found that irrigation, shade, and cool tempeatures are causes of pseudoand aborted flowers in chickpeas.

pseudof lowers per plant. Mean values were 22.9, 12.7, and 8.8 from fully shaded to unshaded. Shading also increased flower abortion: 4.6, 2.3, and 1.1 per plant. The effects were similar in all five cultivars.

Temperature. At Hissar during the cool winter weather, with minimum temperatures often below 5° C, (lowering can continue several weeks before pod setting begins. That period of ineffective flowering generally ends as temperatures rise in February-March (ICRISAT Annual Report 1978/79. pp. 125-126). To test the hypothesis that low night temperatures increase flower abortion, we increased temperatures (with transparent plastic enclosures and heating cables) in the field, from December on during the day, during the night, or during both day and night. We raised maximum day temperatures about 3°C and minimum night temperatures about 9°C. In G-543, warm days alone had little effect, but warm nights either alone or in combination with warm days caused earlier podding and increased numbers of pods (Table 7). Similarly, in Annigeri. warm nights led to earlier podding, but warm days also had a marked effect. So, indeed, flower abortion is influenced by temperature, but further investigations will be necessary to determine the relative influences of day and night temperatures and how much the increased humidity in the plastic enclosures influenced pod setting.

Irrigation. At ICRISAT Center, irrigation markedly affected both pseudoflower production and flower abortion. Pseudoflowers averaged twice as many and aborted flowers 10 times as many on irrigated as on nonirrigated plants, but with striking differences among cultivars (Table 8). Some, including ICC-5810. had few pseudoflowers or aborted flowers even when irrigated (3.0 and 2.4 per plant, respectively); others, including Annigeri. had many (32.9 and 22.3 per plant, respectively). Since the infructuous flowers were produced before pod setting began, podding was delayed in cultivars such as Annigeri but in cultivars such as ICC-5810 podding started soon after the plants began to flower (Fig.3). The differences may have adaptive significance, as the effective vegetative phase of

Table 7. Effects of raising the day and/or night temperatures on pod-set in chickpea cultivars Annigeri and G-543 at Hissar, 1981/82.

	Annigeri		G-543	
Treatment	Pod no./m^2 12 Feb	Date podding began	Pod no./m^2 4 Mar	Date podding began
Control	16	12 Feb	12	4 Mar
Warm days	252	18 Jan	113	27 Feb
Warm nights	268	13 Jan	877	17 Feb
Warm days and warm nights	483	8 Jan	966	12 Feb

Table 8. Numbers of pseudoflowers and aborted flowers per plant in eight chickpea cultivars under irrigated and nonirrigated conditions on an Alfisol, ICRISAT Center, 1981/82.

	Irrigated				Nonirrigated			
Cultivar	Pseudo flowers		Aborted flowers		Pseudo (lowers		Aborted flowers	
K-850	10.8	±4.9	0.7	±0.3	2.9	±0.4	0.4	±0.2
ICC-5810	3.0	±0.4	2.4	±0.8	3.9	±0.5	0.3	±0.2
Caina	15.9	±3.3	5.1	±1.2	5.4	±0.7	2.8	±1.1
ICC-8404	28.0	±3.9	7.5	±1.4	11.0	±2.0	1.2	±0.4
ICC-14	13.1	±2.3	10.3	±2.7	10.5	±1.5	1.7	±0.9
ICC-7684	10.5	±2.4	14.4	±2.8	7.0	±1.1	1.1	±0.4
ICC-10445	23.9	±3.8	16.2	±3.5	8.1	±1.3	0.6	±0.2
Annigeri	32.9	±6.9	22.3	±3.5	12.9	±2.1	2.7	±0.7

Annigeri-type cultivars is extended under favorable moisture conditions but ICC-5810-type cultivars are affected relatively little.

Effects of Photoperiod

We studied the effects of extended photoperiod on growth and development by illuminating plants growing in the field with electric lights all night every night from seedling emergence until the reproductive phase began (Fig.4). Chickpeas, quantitative long-day plants, flower sooner under extended photoperiods(ICRISAT Annual Report 1979/80. pp. 79-81). Early cultivars are affected relatively little: this year Annigeri flowered 3 days earlier at ICRISAT Center and 8 days earlier at Hissar under an extended photoperiod. But late cultivars such as G-130 flowered 30 and 40 days earlier, respectively, at ICRISAT Center and Hissar.

Photoperiod affects not only the phenology of the plants but also their morphology. Even before they flowered, the plants showed strikingly different vegetative growth patterns. At ICRISAT Center, the medium L-550 and the late G-130 had larger leaves and were more upright and less branched when illuminated at night than under normal conditions. Indeed, the plants resembled the early Annigeri in both phenology and general appearance (Fig.5).

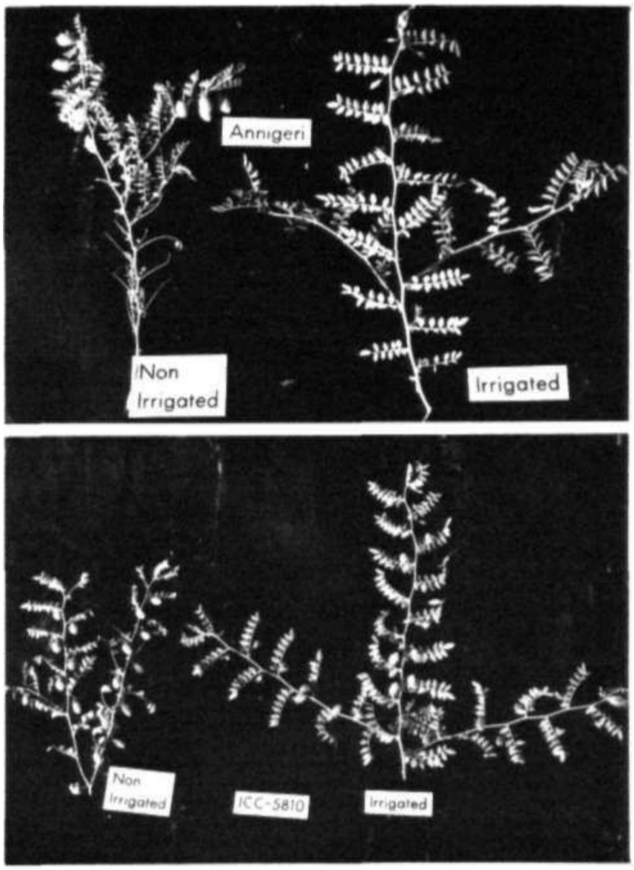
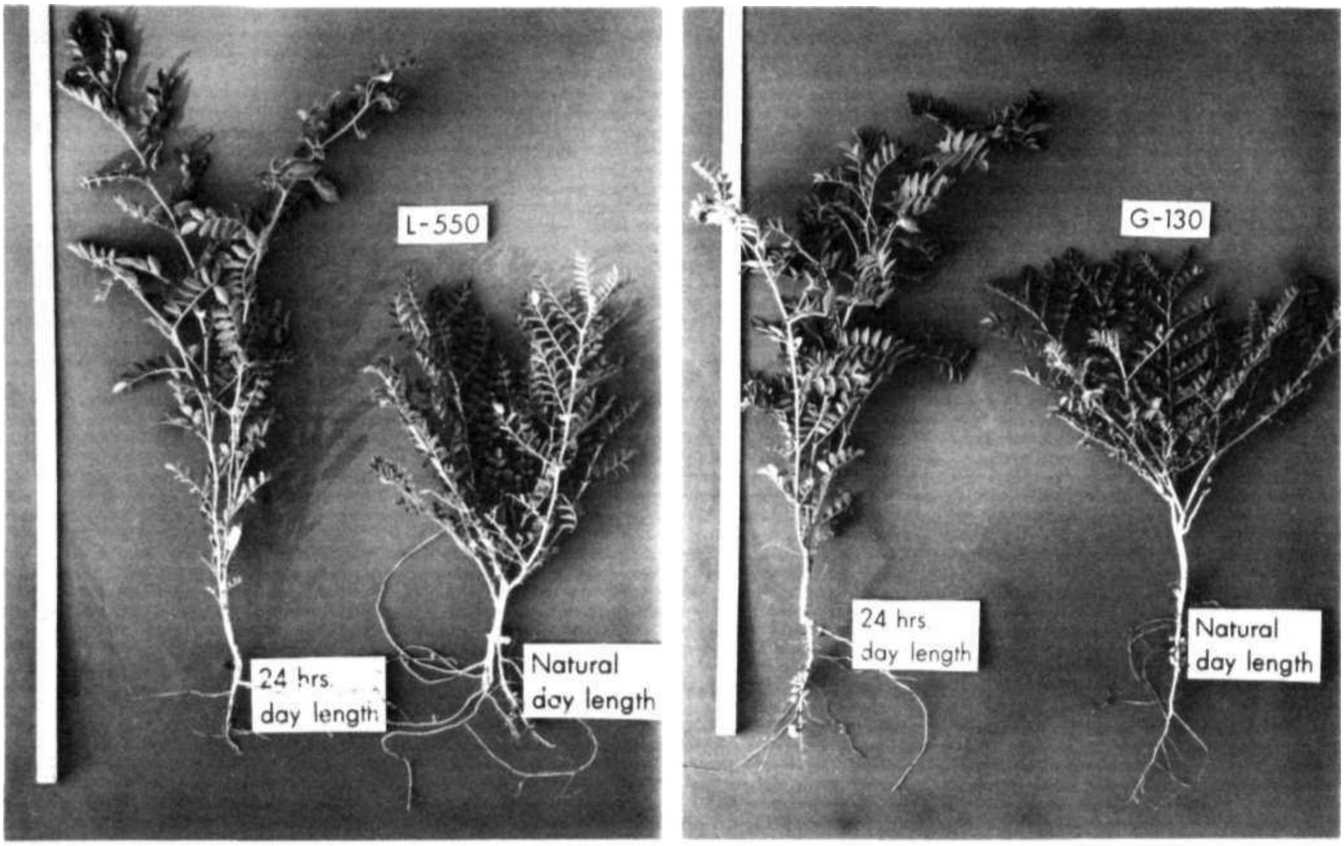
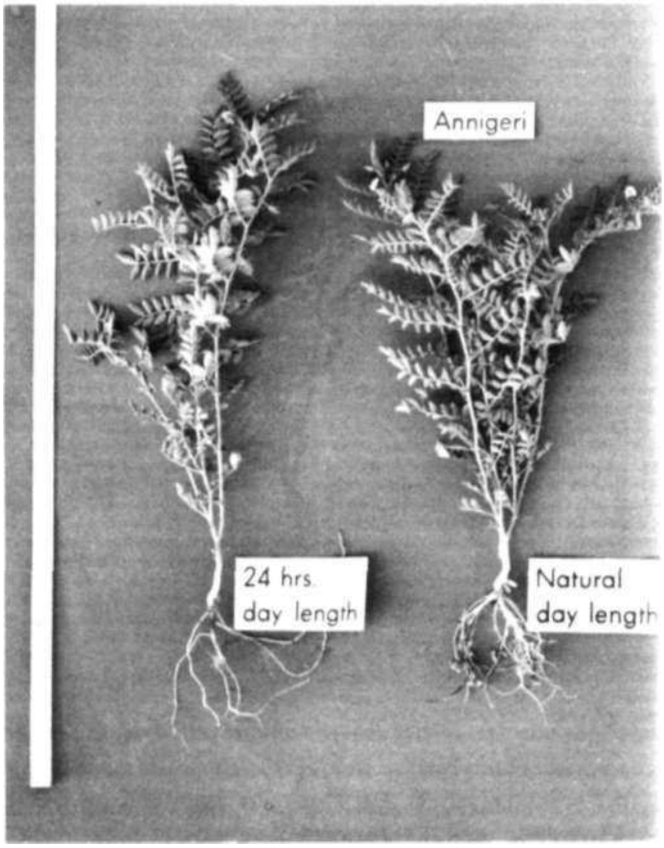


Figure 3. Irrigating chickpeas increasing both pseudo and aborted flowers but at widely different rates in different varieties. Annigeri, for example, produced 33 pseudo and 22 aborted flowers per plant, while ICC-5810 produced only 3 and 2, respectively. Shading also increases pseudo and aborted flowers.





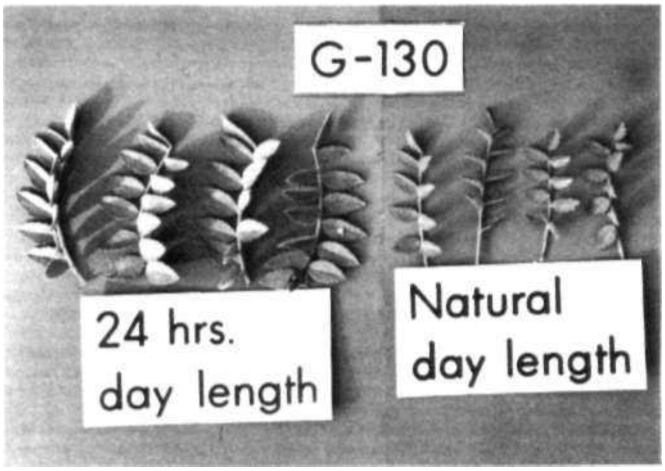


Figure 5. In each photo, chickpeas on the left were exposed to 24-hour days; those on the right to natural daylengths. L-550, a medium-maturing variety, and G-130, a late maturity one, produced larger leaves, grew more upright, and branched less under 24-hour days than under natural light, so they resemhled Annigeri, the standard early-maturity chickpea. Under 24-hour days, G-130 flowered from 30 to 40 days earlier than under natural days. Annigeri out-yielded the others.

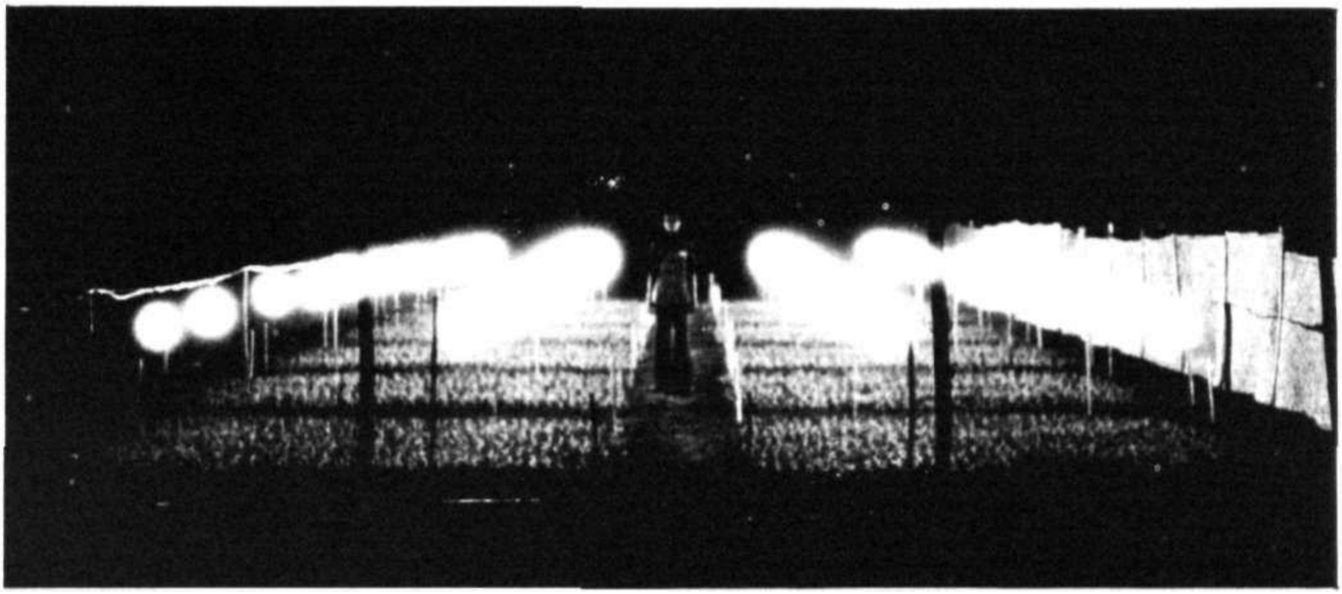


Figure 4. Chickpea under electric lights that extended daylength to 24 hours at ICRISAT Center matured earlier but tended to yield less than those under natural daylengths.

Under normal day lengths, Annigeri matured sooner than, and significantly outyielded, the other cultivars (Table 9). With extended photoperiod, all three cultivars matured more or less simultaneously, but Annigeri still gave the highest yield, which indicated that its superiority over the later cultivars depends on its growth duration being close to optimum and on other physiological factors.

Biological Nitrogen Fixation

Rhizobium Collection

The collection, now maintained in freeze-dried ampoules, has continued to be a source of strains for research workers in India and overseas.

Surveys

Poor nodulation in farmers' fields as indicated in our previous nodulation surveys (ICRISAT Annual Report 1975/76, p. 139) may stem from several factors such as insufficient soil moisture, high or low temperature, or absence of, or poor performance by, *Rhizobium.* We extended the technique of counting chickpea rhizobia (ICRISAT Annual Report 1977/78, pp. 17-18 and p. 134) to farmers' field surveys in January and February 1982. Five of 18 farmers' fields in Gwalior district and 9 of 18 in more traditional growing areas between the Rajasthan canal and Hissar had low populations of chickpea rhizobia. Correlations between nodule number per plant and soil *Rhizobium* population were not statistically significant but poor nodulation was always associated with low rhizobial populations, so soil *Rhizobium* population counts may be useful in assessing inoculation needs.

Strain Evaluation and Success of Inoculation

Past experience at ICRISAT indicates that plant growth and yield responses to *Rhizobium* inoculation are minimal in soils containing high populations of chickpea rhizobia (> 10^3 rhizobia per g soil). To differentiate effects of inoculation treatments on plant growth, we conducted strain testing experiments in 1981/82 at ICRISAT Center on Alfisols that were free of chickpea rhizobia and low in soil N. But the experiments revealed problems not previously observed where natural populations had masked inoculant effects.

Table 9. Effects of 24-hr photoperiod on flowering, maturity, and yield of three chickpea cultivars, ICRISAT Center, 1981/82.

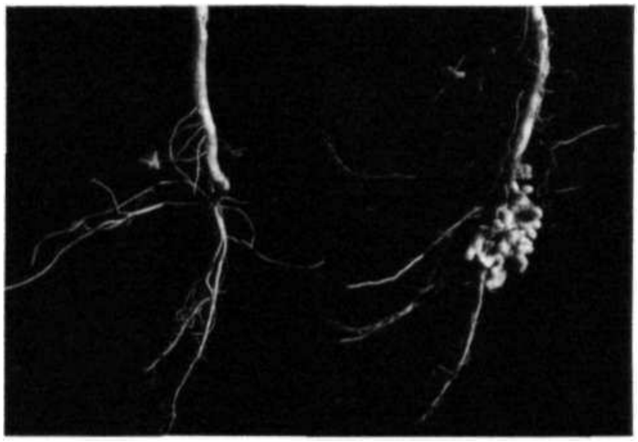
	Days to 50% flowering		Days to maturity		Yield (kg/ha)	
Cultivar	Control	24-hr day	Control	24-hr day	Control	24-hr day
Annigeri	33	29	87	75	1860	1420
L-550	52	33	95	72	1030	1090
G-130	66	36	102	75	1130	1010
SE within cultivars	±0.3		±0.3		±71	
SE within treatments	±0.4		±0.9		±65	

In an experiment conducted as part of AICPIP, K-850 produced greater nodule mass and seed yields than Annigeri or BDN-9-3 (Table 10). The three inoculants used (H-45, F-75, and IC-76) each increased nodule mass and seed yield. H-45 produced the greatest increase in nodule mass; IC-76, the least. Strain x cultivar interactions were not significant. Other nodulation characteristics responded similarly to nodule mass.

At 20 days after sowing, however, nodulation was poor even with the best strain. The coats of

Table 10. Nodulation (74 days) and seed yield of three chickpea varieties inoculated with three *Rhizobium* strains, ICRISAT Center, 1981/82.

Rhizobium strains	Annigeri	BDN-9-3	K-850	Mean
	Nodule dry weight mg/plant			
IC-76	40	28	69	46
H-45	77	92	127	98
F-75	48	77	106	77
SE		±15.5		±8.9
Mean	55	66	10!	
SE		±8.9		
Noninoculated	2	6	0	
Urea (150 kg N/ha)	0	0	2	
	Seed yield (kg/ha)			
IC-76	1240	900	1160	1100
H-45	1310	1020	1410	1250
F-75	1030	970	1320	1110
Control	700	640	810	720
Urea	1380	1420	1690	1500
SE		±120		±69
Mean	1130	990	1280	
SE		±54		



Roots of chickpea plants show nitrogen-forming nodules (right) after being treated with an effective inoculum. Roots on the left from a noninoculated plant.

germinated seeds carried at least 10^4 rhizobia per seed, indicating that nodulation failed because rhizobia did not move into the rooting zone. Rhizobia apparently moved only after irrigation, which was confirmed later in a glasshouse pot study. Most chickpeas are grown on residual moisture in the semi-arid tropics, so we are initiating experiments on alternative methods of applying *Rhizobium.*

Urea at 150 kg N/ha significantly increased yields and seed protein contents over the inoculated and noninoculated treatments (Table 11). Seed protein content was greater in inoculated than in noninoculated plots and in BDN-9-3 than in Annigeri or K-850. Genotypes ranked similarly in all nitrogen regimes, confirming previous indications of the absence of genotype x environment interactions for seed protein content.

Serological Studies

A study involving a mixed inoculum provided by NifTAL clearly showed the dominance of one strain in *Rhizobium-free* soils. Difficulties in preparing antisera prevented more extensive use of the technique, which is being investigated further.

Effect of Soil Temperature

We varied the soil temperatures for chickpea plants in pots containing Vertisol soil with high *Rhizobium* counts by immersing the pots in water baths of 25°, 30°, 32°, and 35°C for 8 hr/day, beginning 6 days after sowing. Nitrogenase activity, nodule number and mass, and top dry weight declined as temperature increased (Table 12, Fig.6), suggesting that the poorer nodulation in chickpeas sown early at ICRISAT Center may stem from high September soil temperatures (ICRISAT Annual Report 1977/78, p. 173). High-temperature effects may be mitigated by irrigation, which has consist-

Table 11. Protein percentages of seeds of three chickpea cultivars in differing nitrogen regimes.

Treatment	Annigeri	BDN 9-3	K-850	Mean
H-45[a]	17.2	20.1	18.5	18.6
F-75[b]	17.5	19.2	17.8	18.2
IC-76[c]	17.8	20.4	18.1	18.7
Noninoculated	14.5	16.8	15.5	15.6
Urea (150 kg N/ha)	22.6	25.7	23.4	23.9
SE		±0.56		±0.33
Mean	17.9	20.4	18.7	
SE		±0.25		

abc. Rhizohium strains.

Table 12. Effects of soil temperature on nodulation, N_2-fixation, and plant growth of chickpea.

Temperature (°C)	Nitrogenase activity (μ M C_2H4/pot per hr)	Nodule (no./pot)	Nodule dry wt (g/pot)	Top dry wt (g/pot)
25	22.7	1480	1.95	21.9
30	11.1	1580	1.55	16.9
32	4.7	1490	1.33	10.4
35	2.2	800	0.83	6.8
SE	±1.79	152	±0.163	±0.74
CV (%)	35	23	23	II

ently improved nodulation and yield (ICRISAT Annual Report 1979/80, p. 83). We plan to start screening for strains that fix nitrogen at high temperatures (30° to 35°C).

Screening for Nodulation

To determine the basis of chickpeas' variability, we will assess nodulation characteristics of plant progenies showing high and low nodulation in controlled conditions.

Figure 6. A test with soil temperatures varied from 25° to 35°C for 8 hours daily in a Vertisol with many nitrogen-forming bacteria indicated that poor nodulation in chickpeas sown early may stem from high September soil temperatures. Several measures of growth and vigor declined as temperature increased.

Grain and Food Quality

Cooking Quality

We evaluated dhal samples of 14 desi and 4 kabuli cultivars for cooking time, water absorption, percentage of solids dispersed, and Instron force. Desi cultivar cooking times ranged from 22 to 32 min; kabuli's from 22 to 26 min.

Differences (assessed by five panel members) were small between such organoleptic qualities as color, taste, flavor, and texture of desi and kabuli dhal samples (Table 13).

Protein Quality

The analyses of 60 cultivars for total sulfur (leco sulfur analyzer) and methionine (colorimetric procedure) showed no significant relationship between those two constituents, confirming previous data. Methionine contents (determined by the rapid colorimetric procedure) of defatted dhal samples of 1393 accessions ranged from 0.77 to 1.69 with a mean of 1.19 g/16 g N.

The nitrogen accumulation patterns of low (Annigeri) and high (T-1-A) protein cultivars indicated that Annigeri is more efficient in protein yield per plant. T-l-A had higher percentages of nitrogen in the root, stem, leaf, and seed samples than Annigeri, at all stages of growth except for roots and leaves of Annigeri containing more nitrogen in the early stages (Fig. 7).

Table 13. Organoleptic qualities[1] of dhal from desi and kabuli chickpea cultivars.

Cultivar	Color	Taste	Flavor	Texture	General acceptability
Desi					
JG-62	1.8	2.2	2.3	2.8	2.3
Annigeri	2.5	2.8	2.6	2.3	2.7
Pant G-114	2.8	2.3	2.8	2.8	2.8
Kabuli					
L-550	2.7	2.8	2.6	2.4	2.8
ICCC-24	2.6	2.7	2.6	2.3	2.7
ICCC-25	2.8	2.8	2.5	2.3	2.8
SE±	0.15	0.14	0.14	0.16	0.13

1. Rating scale: 3 = good; 2 = fair; 1 = poor. Means of two replicates, evaluated by five panel members.

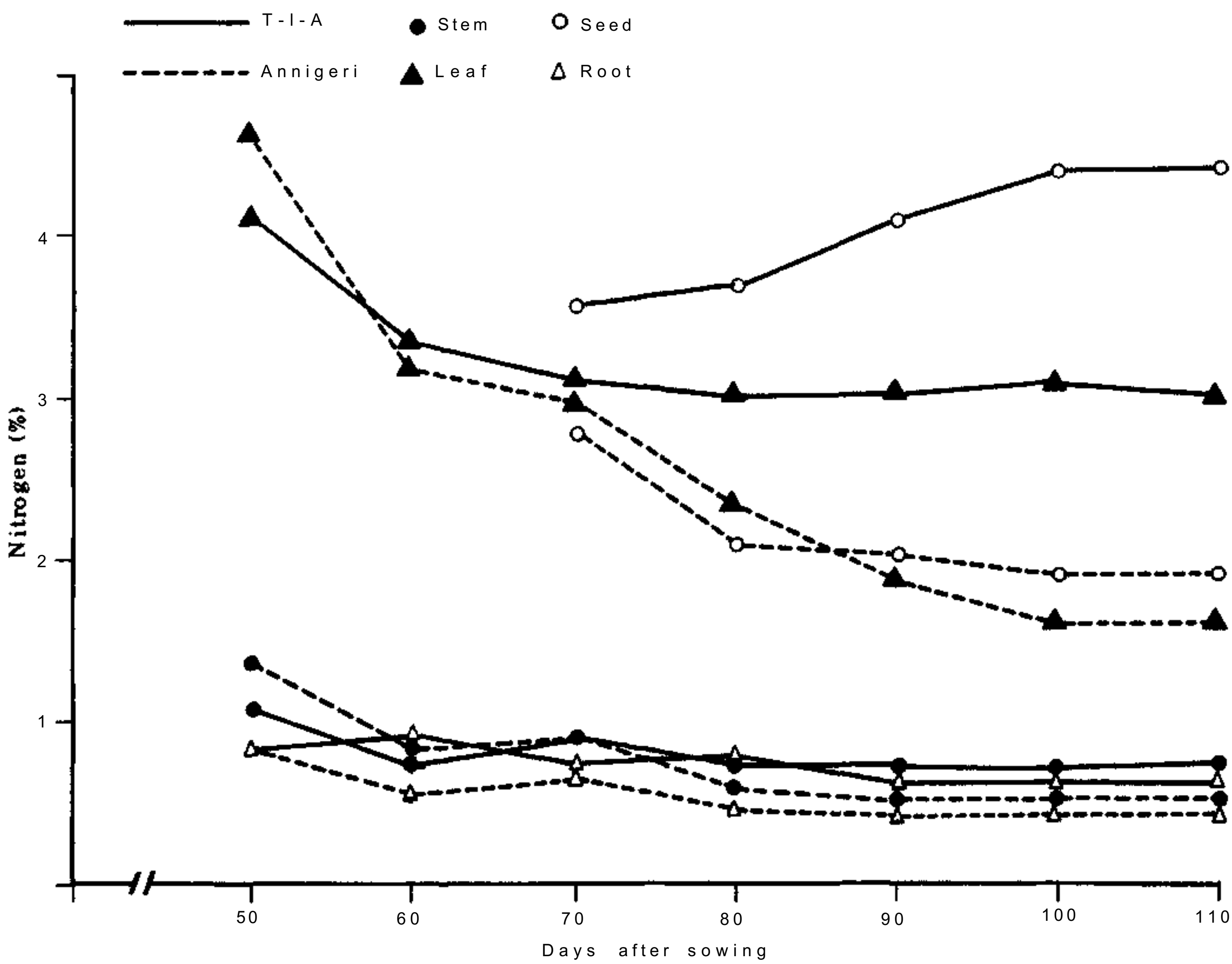


Figure 7. Nitrogen content various tissues of T-1-A and Annigeri chickpeas at indicated stages of growth.

Dry-matter accumulation and nitrogen uptake per plant in T-1-A were considerably higher than in Annigeri. Starch accumulation was markedly higher in seeds of Annigeri but soluble sugars were higher in T-1-A seeds at all stages of seed development. Annigeri yielded three times as much as T-1-A. Increased accumulation of starch in the seeds of Annigeri appears to be responsible for its decreasing seed protein percentage during development, but we found no evidence that the higher seed protein in T-1-A stems from mobilizing and translocating more of its leaf nitrogen. Annigeri's protein yield per unit area is higher than T-1-A's.

We continued to monitor seed protein contents of advanced breeding lines, to ensure that they do not fall below those of existing cultivars. The protein contents of 1603 samples ranged from 12.3 to 31.3%.

The seed protein percentages reported for the germplasm collection are based on seed harvested from unreplicated sets in different seasons, so both seasonal and field variations may distort the data. To assess such distortions, we grew a replicated trial of germplasm accessions (considered high or low in seed protein percentage based on single tests in four seasons) and determined protein contents of the duplicate seed samples harvested from each plot. Correlations were high ($r = 0.90$, $P < 0.01$), confirming the accuracy and repeatability of the estimation. Although significantly greater than zero, correlations between replicates ($r = 0.51$, $P < 0.01$) and present and previous determinations ($r = 0.31$, *P* -0.01) were much lower, which confirms the importance of environmental effects on seed protein and indicates that we need to review our methods of evaluating for meaningful, comparable estimates of this and other characteristics.

Progenies of crosses involving T-I-A produced significant negative correlations between seed size and protein content. We selected those combining moderate seed size with high protein content in F_2 to F_4 generations involving T-I-A for further testing. None of the progenies of crosses involving parents other than T-1 -A exhibited high protein content, so all were discarded.

Antinutritional Factors

To study the effects of cooking on protease inhibitors, we used dhal samples of 16 cultivars, uncooked and cooked under pressure for 15 minutes, then assayed for trypsin inhibitor and chymotrypsin inhibitor activity (Table 14). Heat under pressure destroyed more trypsin inhibitor than chymotrypsin inhibitor activity, but neither was completely destroyed during cooking. In vitro protein digestibility in uncooked samples ranged from 52.1 to 65.1%; and in cooked samples, from 64.1 to 75.8%.

Pod Borer Susceptible and Resistant Cultivars

Polyphenols compounds were estimated in immature and mature seed samples of chickpea

Table 14. Effects of pressure cooking for 15 minutes on trypsin and chymotrypsin inhibitor activities[1] and in vitro protein digestibility in dhal samples of 16 chickpea cultivars.

	Uncooked			Cooked		
Constituent	Range	Mean		Range	Mean	
Trypsin inhibitor activity[1]	9.6-21.1	15.3	±0.83	0.1- 0.9	0.4	±0.04
Chymotrypsin inhibitor activity[1]	3.1- 3.5	3.3	±0.03	0.2- 0.6	0.4	±0.02
In vitro protein digestibility (%)	52.1-65.1	58.5	±0.91	64.1-75.8	70.6	±0.65

1. Units inhibited per mg meal.

cultivars ICC-506 and Annigeri, considered respectively resistant and susceptible, to pod borer (*Heliothis armigera*). Mature seeds of ICC-506 contained more polyphenols compounds than Annigeri, but there were no differences in immature seeds. High-performance liquid chromatography and other procedures revealed no qualitative differences between the two cultivars.

Plant Improvement

Breeding Methodology

Tests at ICR1SAT Center of F_6 families selected from six crosses (Caina x Ponaflar, JG-221 x F-404, P-324 x ICCC-5, B-106 x NEC-989, P-790 x P-1798, F-496 x F-404) advanced by pedigree, bulk, or single-pod descent matured too late for peninsular India and suffered severe plant mortality due to wilts and root rots, so we discontinued the study.

Data were recorded on random plants of F_4 bulks of single- and three- and four-way crosses among Annigeri, ICCC-1, ICCC-2, and K-850 to study the variability generated by multiple crosses. Significant differences among entries were recorded for all characters; the differences arose from among, rather than between, groups. There were alsodifferences within groups in variances, but multiple crosses gave no clear advantage over single crosses except for yield per plant, where three-way crosses exhibited the highest variances. Highest variances for seed size were in crosses involving K-850, which is much larger-seeded than the other parents.

F_3 bulks and progenies of crosses among three desi (CPS-1, Pant G-1 14, and BG-203) and three kabuli (C-104, K-4, and P-9800) genotypes were grown in replicated tests at ICRISAT Center and Hissar. Wilt and root rots attacked the ICRISAT Center plots and ascochyta damaged those at Hissar, so they will be repeated as F_4 bulk trials in 1982-83.

Off-season Nurseries

At ICRISAT Center, we advanced 155 F,s and 58 F_3/F_4 bulks from different projects. At Tapperwaripora, we sowed 849 F_1s, which included: 1) diallel and line x tester series of crosses of desi and kabuli and plant type projects, 2) materials for early- and late-planting projects and inheritance studies, and 3) crosses to incorporate wilt, stunt, ascochyta, and *Heliothis* resistance into improved backgrounds. We also multiplied 288 F_3 progenies and 197 F_2 to F_5 bulks.

Breeding Desi Types

Using line x tester sets between established and new cultivars and diallel sets of new cultivars, we made 316 crosses involving established and new short- and long-duration desi cultivars.

More than 8000 populations and progenies were evaluated at ICRISAT Center and Hissar (Table 15). F_1 and F_2 tests of line x tester sets at ICRISAT Center confirmed previous indications that genetic variation in chickpea is predominantly additive except for such characteristics as number of primary branches, pods, seeds, and seed yield per plant, for which additive and nonadditive effects are important.

Sixty-one F_2s and 129 F_3s in the short- and medium-duration categories were evaluated in replicated trials at ICRISAT Center and Gwalior, and 61 F_2s and 166 F_3s of the long-duration group at Gwalior and Hissar. Three F_2 and five F_3 populations gave numerically higher seed yields than the control. Other populations' seed yields were either similar to or lower than the controls. Ascochyta blight at Hissar, and soil variation at Gwalior prevented meaningful analyses. The best entries were advanced for further testing and selection in 1982/83.

Progenies with sufficient seed were evaluated in two plantings. At ICRISAT Center, one planting was under insecticide-free conditions; at Hissar, to vary the environments, the two plantings were on different dates. More than 6300 single plants at ICRISAT Center and 1691 at Hissar were selected from the F_4 and more advanced generations for evaluation in progeny

Table 15. Numbers of desi populations and progenies grown at ICRISAT Center and Hissar, 1981/82.

Generation	ICRISAT Center		Hissar		Total	
	1st planting	2nd planting	1st planting	2nd planting	1st planting	2nd planting
F_1	158	-	44	-	202	-
F_2	61	-	156	-	217	-
F_3	127	-	166	-	293	-
F_4	70	-	236[a]	-	306	-
F_5	3315	2364	991	573	4306	2937
F_6	1760	1556	493	271	2253	1827
F_7	215	195	142	125	357	320
F_8	53	53	68	68	121	121
F_9	-	-	59	59	59	59
Total	5759	4168	2355	1096	8114	5264

a. Includes 144 progenies and 92 populations.

rows; 277 progenies were bulked for international nurseries and trials next season.

Two preliminary trials of short-duration materials (including introductions from other centers, germplasm selections, and advanced breeding material) were conducted at ICRISAT Center, and two of long duration entries at Hissar. Ascochyta blight destroyed the trials at Hissar. At ICRISAT Center, stands were variable due to wilt and salinity. Germplasm and lines from other centers yielded more than the control. Among 10 derivatives of interspecific crosses, 3 lines were as early flowering as Annigeri, and gave similar yields. They will be tested further next season.

Breeding Kabuli Types

Kabuli materials, evaluated at Hissar and Gwalior, were so badly damaged by ascochyta blight at Hissar that yield data were not analyzable.

We made 25 crosses involving at least one kabuli parent, evaluated in replicated tests F_2 and F_3 line x tester sets of crosses made the two previous seasons, and advanced 92 for further tests in 1982/83. Of more than 1200 F_3 and more advanced bulks and progenies grown, we selected nearly 600 plants and bulked 28 rows for replicated tests next season. We also evaluated 134 lines in replicated trials and selected the best for further tests.

Extending Adaptation of Chickpea

Early sowing. Screening of genotypes for early sowing in peninsular India continued at ICRISAT Center.

A diallel set of crosses was made among seven lines that had performed consistently well under early-sown conditions in previous seasons; they and five other lines were crossed onto three sources of wilt and root-rot resistance.

We also advanced 19 F_1 and 27 F_2 populations of earlier crosses, sowed 248 new germplasm lines early in replicated trials, and repeated our comparison of the previously identified lines under normal and early-sown conditions.

The sowing, in mid-September, was followed by 7 days of heavy rain that caused seed rotting and depressed emergence so much that the experiments were discontinued; the trials will be repeated in 1982/83.

High-input and late-sown conditions in northern India. The search for lines adapted to high-input situations and late sowing in northern

India continued at Hissar but severe damage from ascochyta blight prevented meaningful conclusions. The tests will be repeated.

Plant Type

Tall, erect habit. Selecting for improved yield potential continued in populations involving tall types, which offer advantages for mechanical cultivation.

We made 69 crosses between 8 tall and 9 new desi and kabuli cultivars. At ICRISAT Center, replicated tests of the F_1 9 x 5 line x tester and 6 x 6 diallel sets made the previous season were conducted; the data indicated that variation was predominantly additive except for plant height. In the line x tester, K-56567 was a good general combiner for plant height; ICCC-13, for pod number and seed yield. The Hissar trial provided no data because of ascochyta blight.

Sixty-five F_2 populations and 1116 F_3 to F_8 progenies from previous crosses suffered poor emergence due to poor seedbed preparation so selections, which will be grown as progeny rows (1082) in 1982/83, were confined to single plants.

At Hissar, we grew replicated tests of line x tester and diallel set F_1s; 69 F_2 populations; 1132 F_3 to F_8 progenies; and a replicated trial of 25

Traditionally, short chickpeas (foreground) are known to he high yielding. ICRISAT scientists study tall chickpeas (background), known to he useful for mechanical harvesting and closer planting, to exploit their physiological traits and to improve yields.

Our work on selection to combine double-podded and multiseeded characters in chickpea continued, at both ICRISAT Center and Hissar. Seeds per pod are counted in pod samples harvested, and progenies with most seeds per pod advanced further.

tall, advanced lines. Analyzable data were not obtained owing to ascochyta blight, but the best lines and single plants were advanced for further tests in 1982/83.

Double-podded and multiseeded types. Selection to combine the double-podded and multiseeded characters continued. We made 38 three-way crosses of multiseeded and double-podded F_1s and 13 multiseeded F_1s onto short- and long-duration desi cultivars to introduce the characters into adapted backgrounds.

The replicated trials of F_1 and F_2 generations of a 6 x 6 diallel cross among multiseeded lines and the F_1 generation of a multiseeded (6) x double-podded (5) line x tester set were grown at ICRISAT Center and Hissar. High plant mortality, caused by wilt at ICRISAT Center and ascochyta blight at Hissar, resulted in variable, poor stands, and nonvalid data in both trials. The replicated trial of F_2 generation of 6 x 6 diallel will be repeated at both locations in 1982/83.

At ICRISAT Center, 47 F_2 populations were grown and 1083 individual plants selected. We also evaluated 1955 F_3 and F_4 progenies; those with the most seeds per pod will be further tested in 1982/83.

At Hissar, we selected single plants in 53 F_2 and 22 F_3 bulks of an earlier line x tester set, and grew 1063 F_3 and F_4 progenies and harvested pod samples from each to count seeds per pod. Those with the most seeds per pod will be advanced for further testing and selection.

Inheritance Studies

Parents, F_1s, and F_2 populations of five crosses to study the inheritance of susceptibility to iron chlorosis were grown at ICRISAT Center. The normal parents (Annigeri, K-850, G-130, H-208, and BDN-9-3) and the F_1s were all normal and the chlorotic parent (NP-62) showed chlorosis. Although the numbers of normal and chlorotic plants in three of the F_2s and overall were consistent with the segregation of a single gene with susceptibility recessive, the cross with H-208 gave a large excess of chlorotic plants and that with BDN-9-3, an excess of normals (Table 16). F_2s and F_3 progenies will be examined further in 1982/83.

Segregation of normal and pedicel mutant individuals in F_2 populations indicated that the character's inheritance is controlled by a single recessive gene.

Table 16. Numbers of normal and chlorotic plants. chi-square values, and probabilities of goodness of fit to a 3:1 ratio in F_2s of chickpea crosses (NP-62 x normal parents).

	Plants (no.)			
Cross	Normal	Chlorotic	X^2	P
NP-62xAnnigeri	173	41	3.61	0.1-0.05
NP-62 x K-850	133	37	0.79	0.3-0.5
NP-62 x G-130	47	23	2.87	0.1-0.05
NP-62 x H-208	155	89	17.13	<0.01
NP-62 x BDN-9-3	159	35	5.35	<0.05
Total	667	225	0.05	0.7-0.9
Heterogeneity			23.40	<0.01

Cooperative Activities

Materials distributed to cooperators and contacts with other programs continued to increase. In developing our policy to tailor materials to specific situations, we distributed populations segregating for ascochyta blight resistance to Pakistan and to Punjab, India, and separated the early generation bulk tests into short- and long-duration materials.

International Trials and Nurseries

We distributed 138 sets of trials and nurseries to 46 cooperators in 16 countries (Table 17).

Trials of the long duration group were in areas where ascochyta blight was more or less epidemic. Except for identifying a few entries with some resistance, we got analyzable data from only three locations.

In the short duration group, among the F_2 populations several yielded similar to or better than local controls at each site. Eleven of the best and the poorest were selected for 1982/83 F_3 trials in short-and medium-duration categories. Correlations between performances of the F_3 and F_2 populations of the same crosses in 1981/82 again were poor, confirming the need to test in more than one season. All were carried forward for single-plant selection at ICRISAT Center next season.

In ICSN-DS, yields of entries at each site were similar to or better than the controls. Overall ICCL-81243 from a cross of C-235 and JG-221 was highest yielding. The best nine entries in the short- and medium-duration groups will be repeated in ICSNs next season. Four ofthe best performers during the last 2 years, including ICCL-80074, have been submitted for coordinated trials. The results of ICCT-DS received to date indicate the highest yield for ICCL-78055 followed by BDN-9-3 and ICCC-8.

A series of adaptation trials was grown for the first season, in cooperation with ICARDA. They included a range of desi and kabuli genotypes of wide geographical origin, which, in conjunction with environmental analysis, will help us interpret variation in yield and refine our

Table 17. International chickpea trials and nurseries distributed by ICRISAT in 1981/82.

Country	Trial/Nursery										Total
	F_3MLT-DS	F_2MLT-DL	F_3MLT-DS	F_3MLT-DL.	ICSN-DS	ICSN-DL.	ICCT-DS	ICCT-DL.	CAT	PTPMT	
Bangladesh	1		1		4		2			4	12
Bulgaria									1		1
Burma					1		1				2
Canada									1		1
China									1		1
Ethiopia	1		1		1	1	1	1			6
Ghana							2				2
Honduras			1	1			1				3
India	6	6	8	11	16	14	5	9	8	4	87
Kenya					1						1
Lesotho							1	1			2
Mexico								1			1
Nepal								2			2
Pakistan		3		3		4		4			14
Tanzania							1				1
Zambia					2						2
Total	8	9	11	15	25	f9	14	18	11	8	138

selection and testing strategy. Eight sets were grown in India and complete data obtained from four of them. Even this limited set emphasizes environmental effects on performance and diverse reactions of the few genotypes tested. All the data will be included in our international nurseries report.

International Disease Nursery

The 60 entries in International Chickpea Root Rots/Wilt Nursery (ICRRWN) for 1980/81—originating in four countries and ICRISAT Center—were sent to 34 locations in 18 countries. Data were returned from 21 locations in 9 countries. Detailed results of this nursery are available separately (Pulse Pathology Progress Report No. 19). Two entries (ICC-267 and -11551) performed well across 13 locations; three entries (ICC-858, -9023, and -9032) across 12 locations; and six (ICC-2858, -2862, -6494, -10803, -11088, and -11550) across 11 locations. All other entries did well across several locations.

Distribution of Breeders' Material

In addition to the trial and nursery sets, we supplied 2889 parental lines and segregating materials to centers in India and other countries.

Cooperation with ICARDA

An ICRISAT staff position, created for a chickpea pathologist at ICARDA, was filled in September.

Surveys indicated that the leaf miner, *Liriomyza cicerina,* was, as usual, widespread in most fanners' fields in Syria. We continued attempts to quantify yield losses it causes. *Heliothis* spp. were again of minor importance in northern Syria but in southern Syria they seriously damaged crops, and several farmers used pesticides on the crop. *Heliothis armigera* and *Heliothis viriplaca* were found on chickpea in roughly equal numbers. The latter entered pupal diapause in April and May and emerged the next spring. In Tunisia, Algeria, and Morocco leaf miner damage was common and severe enough to reduce yields in some areas. *Heliothis* spp. were rare on chickpea during our visit but the national scientists said that those pests are extremely damaging in some areas and years.

Around 5000 desi germplasm accessions and 25 F_2s of crosses between ascochyta blight resistant desi types and north Indian desi and kabuli cultivars were screened in an ascochyta blight nursery at Tel Hadya. Under the extreme disease conditions that occurred, pod damage was high so only a few germplasm accessions, and no F_2 populations, were rated resistant.

We provided 101 advanced kabuli lines to assess the potential of northern Indian materials for winter sowing. Growth was affected by unusually low temperatures and dry conditions in March and April, and most of the genotypes showed symptoms of iron chlorosis but a few yielded more than the local controls, indicating some potential of northern Indian material for winter sowing in the Mediterranean region.

See the "International Cooperation" section of this annual report for a fuller review of cooperative work with ICARDA.

Cooperation with AICPIP

We screened germplasm lines and breeding materials from scientists of All India Coordinated Pulses Improvement Project (AICPIP) for resistance to fusarium wilt and other soilborne diseases, and communicated the results to the scientists.

Five new entries were contributed to the Gram Initial Evaluation Trial (ICCC-27, -28, -29, -30, and -31). ICCC-22 and 1CCC-23 were promoted to Gram Coordinated Varietal Trials in different zones, and ICCC-4 and ICCC-13 were retained in peninsular and central India for the 4th year. ICCC-4 also was included in demonstration plots in Rajasthan, Madhya Pradesh, and Gujarat. And it has been proposed for mini-kit trials in those areas in 1982/83. One set each of the gram coordinated trials was grown at ICRISAT Center.

Two new kabuli lines, ICCC-32 and ICCC-33, were contributed to the Kabuli Coordinated

Variety Trials and ICCC-25 and ICCC-26 were continued for the 2nd year.

We have submitted four new desi lines and one new kabuli line to the coordinated trials 1982/83.

Looking Ahead

Sources of resistance to important fungal diseases and pests have been identified and are now being bred into improved genetic backgrounds. Emphasis will be accorded to resistance to ascochyta blight and botrytis gray mold, the most damaging diseases of chickpea the past two seasons in the main growing areas.

We are recombining Heliothis-resistant sources to increase existing resistance to this pest. It becomes increasingly clear that viruses cause heavy crop losses and merit increased attention.

Physiological studies of the effects of photoperiod and temperature on flowering and pod set and genotypic responses to late sowing are in progress. We hope to develop husbandry practices and genotypes capable of higher and more stable yields, which are vital if chickpea is to compete with wheat in irrigated situations in northern India. The search also continues for genotypes that germinate with limited seedbed moisture and are tolerant to drought stress and salinity. Effective *Rhizobium* strains are being evaluated for competitive ability, and inoculation methods are being studied.

Increasing knowledge of constraints to production is assisting in assembling the disease and pest resistance and physiological and microbiological characteristics necessary for higher and more stable yields in specific environmental situations.

Publications

Institute Publications

NENE, Y.L., HAWARE, M.P., and REDDY, M.V. 1981. Chickpea diseases: resistance-screening techniques. Information Bulletin No.10. Patancheru, A.P., India: ICRISAT.

Journal Articles

HAWARE, M.P., and NENE, Y.L. 1982. Symptomless carriers of the chickpea wilt fungus. Plant Disease 66:250-251.

HAWARE, M.P., and NENE, Y.L. 1982. Races of *Fusarium oxysporum f.sp.ciceri.* Plant Disease 66:809-810.

JAGDISH KUMAR and HAWARE, M.P. 1982. Inheritance of resistance to Fusarium wilt in chickpea. Phytopathology 72(8): 1035-1036.

JAMBUNATHAN, R., and SINGH, U. 1981. Studies on desi and kabuli chickpea *(Cicer arietinum* L.) cultivars -3. Mineral and trace element composition. Journal of Agricultural and Food Chemistry 29:1091-1093.

JAMBUNATHAN, R., and SINGH, U. 1981. Relationship between total sulphur and sulphur amino acids in chickpea (*Cicer arietinum* L.) and pigeonpea (*Cajanus cajan* L. Millsp.). Qualitas Plantarum-Plant Foods for Human Nutrition 31:109-117.

NENE, Y.L. 1982. The outlook for chickpea and pigeonpea. SPAN 25:14-16.

NENE, Y.L., and GOWDA, C.L.L. 1981. Global research on pulses. Indian Farming 31(5):25-27.

SETHI, S.C., BYTH, D.E., GOWDA, C.L.L., and GREEN, J.M. 1981. Photoperiodic response and accelerated generation turnover in chickpea. Field Crops Research 4:215-225.

SINGH, U., and JAMBUNATHAN, R. 1981. Relationship between nonprotein nitrogen and total nitrogen in chickpea (*Cicer arietinum* L.) seed. Journal of Agricultural and Food Chemistry 29:423-424.

SINGH, U., and JAMBUNATHAN, R. 1981. Studies on desi and kabuli chickpea *(Cicer arielinum* L.) cultivars -Levels of protease inhibitors, levels of polyphenolic compounds and *in vitro* protein digestibility. Journal of Food Science 46:1364-1367.

SINGH, U., and JAMBUNATHAN, R. 1982. Changes in starch, oligosaccharides and soluble sugars in developing pod wall and seed of chickpea. Phytochemistry 21:297-299.

SINGH, U., JAMBUNATHAN, R., and SAXENA, N.P. 1981. Changes in carbohydrates, amino acids, and proteins in developing seed of chickpea. Phytochemistry 20:373-378.

SINGH, U., KHERDEKAR, M.S., and JAMBUNATHAN, R. 1982. Studies on desi and kabuli chickpea *(Cicer arietinum* L.) cultivars. - The levels of amylase inhibitors, levels of oligosaccharides and *in vitro* starch digestibility. Journal of Food Science 47:510-512.

SINGH, U., RAJU, S.M., and JAMBUNATHAN, R. 1981. Studies on desi and kabuli chickpea (Cicer *arietinum* L.) cultivars - II. Seed protein fractions and amino acid composition. Journal of Food Science and Technology 18(3):86-88.

Conference Papers

CHALAM, T.V., REDDY, M.V., NENE, Y.L., and SUBBIAH, J. 1981. Identification of cucumber mosaic and bean yellow mosaic viruses in chickpea in India. Presented at the Third International Symposium on Plant Pathology, IARI, 14-18 Dec 1981, New Delhi, India.

HAWARE, M.P., and NENE. Y.L. 1981. Screening for resistance to two root rots of chickpea. Presented at the Third International Symposium on Plant Pathology, IARI, 14-18 Dec 1981, New Delhi, India.

JAMBUNATHAN, R., SINGH, U., and SUBRAMANIAN, V. 1981. Grain quality of sorghum, pearl millet, pigeonpea, and chickpea. Presented at the Workshop on Interfaces between Agriculture, Nutrition, and Food Science, ICRISAT, 10-12 Nov 1981, Patancheru, India.

SAXENA, N.P. 1982. Role of K in drought-tolerance -a global view. Presented at the Group Discussion on 'Potassium and Plant Physiology, 'Potash Research Institute of India, 14-15 Sept 1982, New Delhi, India.

TOOMSAN, B., RUPELA, O.P., and DART, P.J. 1982. Studies on soil and rhizosphere populations of *Rhizobium* sp. nodulating *Cicer arietinum.* Presented at the National Symposium on Biological Nitrogen Fixation, IARI, 25-27 Feb 1982, New Delhi, India.

Miscellaneous

SMITHSON, J.B. (Ed.). International Chickpea Newsletter No.5 (December 1981). 30 pp.

SMITHSON, J.B. (Ed.). International Chickpea Newsletter No.6 (June 1982). 42 pp.

PIGEONPEA

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PIGEONPEA

During 1982 the Pigeonpea Improvement Program continued to develop cultivars, lines, and broad-based populations of early-, medium-, and late-maturing pigeonpeas that can provide higher and more stable yields in the SAT. This report covers the data collected in 1982, most of them from crops planted in 1981. Early-maturity pigeonpeas, normally planted in June or July, are usually harvested before 30 November, so results from them are included. But medium- and late-maturity pigeonpeas planted at the same time as early-maturity ones usually are harvested late in February and April, respectively, so results for their 1982 plantings are not available for the 1982 annual report.

Our major activities were concentrated at four locations: (1) ICRISAT Center at Patancheru (18°N; 760 mm rainfall), with emphasis on medium-maturity types for intercropping with major cereals in central and peninsular India; (2) Hissar station (29°N; 350 mm rainfall), on early-maturity types as sole crop with limited irrigation in pigeonpea-wheat rotations, a new cropping system of northwestern India; (3) Gwalior station (26°N; 900 mm rainfall), on late-maturity types for intercropping in northeastern India; and (4), through contract research, at the University of Queensland, Brisbane, Australia, (27°S; 1092 mm rainfall), to develop short-season pigeonpeas and mechanized production systems for extensive rainfed agriculture. After five productive years, the contract with the University of Queensland is being completed this year, but we expect our close collaboration to continue.

Rainfall in northwestern India during 1982 was less than normal. Our crop at Hissar required one irrigation and apparently drew moisture from the water table, which is around 2-m deep. Except for some pod borers on the earliest pods, insects and diseases did little damage at Hissar.

In 1981 the rainy season generally ceasing early in central and peninsular India caused disappointing yields at ICRISAT Center. Again pod borer attacks on the rainy-season, medium-maturity pigeonpea crop were heavy and podfly attacks were moderate.

In much of the northeastern region, flooding from heavy early rains led to poor crop establishment and heavy phytophthora blight attacks on the early-seeded crop. At our Gwalior station the rainy season ceased extremely early, though late rains helped the crop recover partially—but with highly variable yields. Sterility mosaic, wilt, and podfly continued to take heavy tolls on pigeonpea yields in that region.

Diseases

Surveys

Roving surveys we have made since 1974 in India and four African countries (Kenya, Malawi, Tanzania, and Zambia) indicate that sterility mosaic is the most important pigeonpea disease in India followed by wilt (Figs. 1 and 2), while in three of the four African countries, wilt is the most important (Table 1); our economists estimate sterility mosaic and wilt losses in India at U.S. $113 million annually. In Africa wilt disease has been estimated to cause annual losses exceeding U.S.$5 million.

Wilt

We continued efforts to identify sources of wilt resistance and to use them in the breeding program.

Screening for resistance. Ten of 12 promising early-maturity progenies with less than 20% wilt last year had less than 10% this year. Eighty of an additional 184 early-maturity pigeonpea progenies or lines we screened had less than 20% wilt, and 474 of 2736 new germplasm accessions screened had some resistance. Screening the 157 progenies of resistant plants selected from germplasm in two previous seasons gave 71 selections with wilt resistance; 13 of them have been included in the 1982/83 ICAR-ICRISAT Uniform Trial for Pigeonpea Wilt Resistance (IIUTPWR). Seventy-two late-maturity promis-

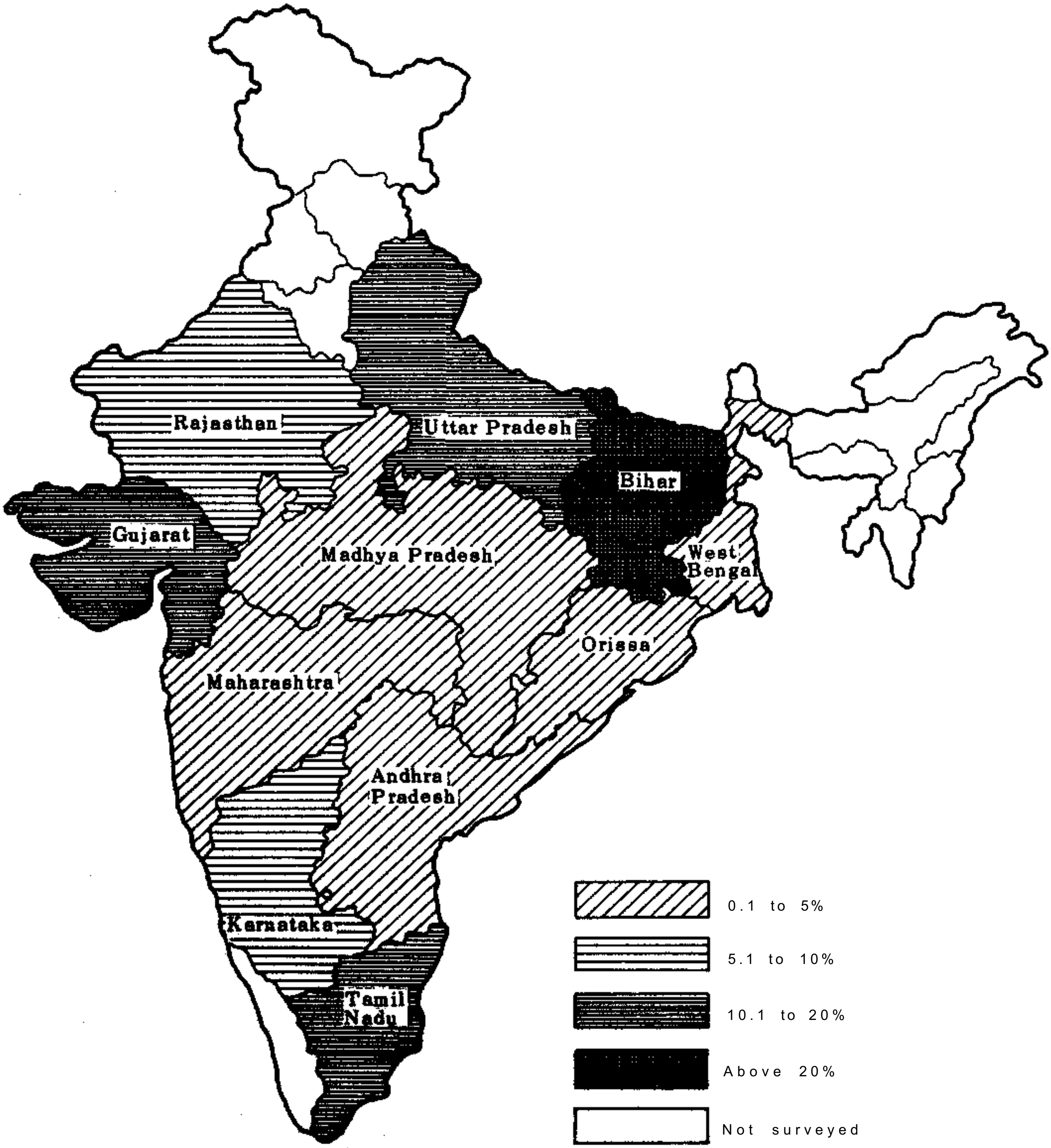


Figure 1. Average incidence (%) of pigeonpea sterility mosaic disease in India, based on ICRISAT surveys, 197580.

ing lines were screened, and 56 showed wilt resistance.

We also screened for resistance to wilt, our accessions that resist sterility mosaic, phytophthora blight, or *Heliothis* pod borer. Of the 49 sterility mosaic resistant accessions screened, 12 had some resistance to wilt. Screening the 52 progenies from wilt-resistant plants selected from sterility mosaic resistant lines during the two previous years gave 33 resistant to wilt. Only 2 of 21 blight-resistant accessions tested, resisted wilt; 17 of 45 accessions with promising resist-

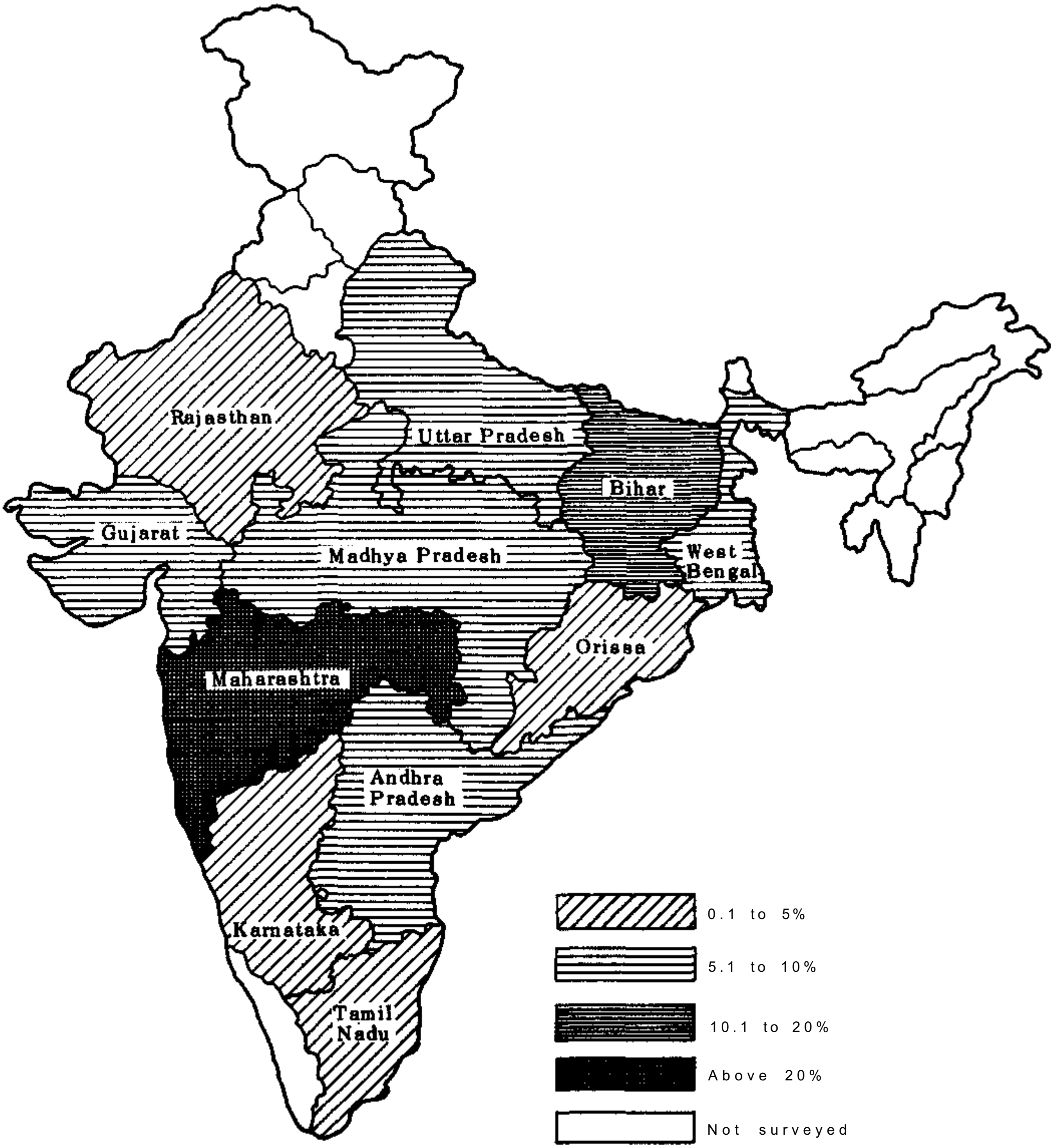


Figure 2. Average incidence (%) of pigeonpea wilt disease in India, based on ICRISAT surveys, 1975-80.

ance to *Heliothis* pod borer also were promising against wilt.

A large amount of breeding material, including F_3 to F_9 progenies, F_3 bulks, early-, medium- and late-maturity advanced materials that had earlier shown some resistance to wilt and elite breeding lines and vegetable types, were screened in the wilt-sick plot. Promising materials were advanced for further testing.

Influence of crop rotation and intercropping. In cooperation with ICRISAT's cropping-systems scientists, we began a 4-year study of crop rotation and intercropping with pigeonpea in the 1978/79 season. In 1981, the 3rd year, pigeonpea intercropped with sorghum had 20.6% wilt in contrast to 63.7% in the continuous sole pigeonpea crop (ICP-6997). But intercropping pigeonpea and maize did not reduce wilt. Sorghum, in a 2-year break between pigeonpea crops, reduced wilt to 10.9% in pigeonpea the 3rd year.

Sterility Mosaic

Causal agent. Our efforts to establish the causal agent of sterility mosaic disease continued. We tried several extraction media and purification procedures to isolate the causal agent.

Table 1. Major pigeonpea disease problems in East African countries in order of severity and frequency.[1]

Country	Distance traveled by road (km)	Locations examined (no.)	Approximate pigeonpea area in the country (ha)	Diseases
Kenya	1500	25	100000	Wilt[2] Cercospora leaf spot[2] Powdery mildew Grey mildew A mosaic A root tumor (gall)
Malawi	1000	20	50000	Wilt[2,3] Cercospora leaf spot[2,3] Powdery mildew[3] Root-knot Phoma stem canker[3]
Tanzania	600	13	35000	Wilt[2] Powdery mildew[2] Cercospora leaf spot Grey mildew[3] Rust[3] Macrophomina stem canker[3]
Zambia	500	6	Not known	Powdery mildew[2,3] Cercospora leaf spot Phoma stem canker[3]

1. Bated on visits in 1980.
2. Diseases considered to merit top research priority in the countries indicated.
3. Although reported previously in other countries, these diseases are reported for the first time in the countries indicated.

Twice we obtained thin flcxuous rod-shaped and rhabdo-type virus-like particles; however, we did not observe such particles in thin sections from sterility mosaic affected leaves. Our efforts to locate a local lesion host, and to establish the cause, will continue.

Biology of the vector. *Aceria cajani* (Channa-basavanna) (=*Eriophyes cajani),* an eriophyid mite, is a vector of the causal agent of sterility mosaic of pigeonpea. After having our research technician trained in the U.S. Department of Agriculture's Boyden Entomology Laboratory at the University of California, Riverside, in handling and rearing eriophyid mites, we initiated work to develop a causal-agent-free mite colony, to help us better understand the mechanism of sterility mosaic disease transmission.

We continued studies on the spread of the disease under field conditions. The mites, carried by wind, spread the disease at least 1000 m with the wind, 200 m against the wind, up to 400 m north, and up to 300 m south. We shall determine if the mites can spread the disease up to 2000 m with the wind.

Screening for resistance. This year we used the infector-hedge technique developed last year, starting with four rows of the susceptible cultivar, NP(WR)-15, planted 15 December 1980, across the wind direction. Plants in the four rows were staple-inoculated and mites allowed to multiply. By mid-June, the normal planting time, the four rows had developed into a hedge with 34% sterility mosaic infection and a plentiful mite population. The disease spread (in a 2-ha screening nursery, monitored with BDN 1 susceptible indicators) was excellent. Infection on BDN 1 rows averaged 99.8%, ranging from 99.5 to 100%.

We screened 224 progenies selected from 81 segregating germplasm accessions since 1976/77, and identified 34 resistant accessions. In addition, we screened 201 progenies selected from segregating germplasm accessions during 1980/81, and found 24 progenies resistant. Of six dwarf lines screened, our selection, 73081-16 D3 -3⊗- B⊗-90-B⊗ and 20 (I05) from Berhampore showed <10% infection. We purified two early-maturing lines for resistance by selecting and rescreening resistant plants from segregating lines. None of the 13 lines screened having resistance to *Heliothis* was resistant to sterility mosaic, although two 1980/81 selections, ICP-3615-E1-3EB and ICP-8130-E1-2EB, showed <10% infection. Of 34 entries in the four All India Coordinated Varietal Trials (EACT, ACT-1, ACT-2, and ACT-3) only one entry, MA-97, showed <10% infection.

The large amount of breeding material screened this year included early-maturity material from Hissar, 113 progenies selected from different crosses, 57 resistant and 230 tolerant F_3 progenies selected from 1980/81 F_2 bulks, 41 resistant and 9 tolerant F_3 bulks, 20 progenies of the cross C 11 x ICP-6997 included in the yield nursery, and 33 advanced lines included in the two yield tests. Of 185 early-maturity Hissar lines,only one,74205-I-104-II-B⊗-H1-HB-HB, was resistant. Six ofthe 57 F_3 progenies screened were resistant; they, along with 22 other progenies selected for resistance, will be yield tested next year. Of the 230 tolerant progenies screened, 67 were uniformly tolerant. Among 113 promising progenies selected from different crosses, 12 progenies—in addition to being resistant or tolerant—yielded more than 2000 kg/ha.

The 387 germplasm accessions, identified at ICRISAT Center as resistant or tolerant to sterility mosaic, were tested for reactions to sterility mosaic at Bangalore in collaboration with a scientist of the University of Agricultural Sciences. All the accessions tested except eight were susceptible, which indicates that a different strain of the causal agent or vector existed at Bangalore. We are investigating the reason for this difference in reaction.

Influence of intercropping. The influence of a sorghum intercrop on sterility mosaic incidence was studied in an experiment in the sterility mosaic nursery. Disease incidence was slightly higher in intercropped than in sole crop pigeonpea up to 75 days after planting (DAP). At 90

Table 2. Sterility mosaic incidence and weather factors in sole pigeonpea and pigeonpea intercropped with sorghum at ICRISAT Center, rainy season 1981.

Cropping pattern	Disease incidence (%) at indicated days after planting[1]					Wind Velocity[2] (km/h)	Relative humidity[2] (%)	Temperature[2] (°C)
	30	55	75	90	125			
Sole pigeonpea	2.3	32.5	48.7	96.7	98.0	5.6	71.7	24.3
Intercropped[3] pigeonpea	3.5	36.1	60.5	96.9	98.3	3.3	72.7	23.7
SE ±	0.5	0.6	6.8	0.4	0.6			
CV(%)	33.0	3.7	24.7	0.9	1.2			

1. Average of four replications.
2. Recorded five times during the day 50 days after planting.
3. One row pigeonpea cultivar BDN 1 to 2 rows sorghum CSH-6.

DAP and later there was no difference. At 50 DAP, wind velocity was lower in the intercropped pigeonpea than in the sole crop, although relative humidity and temperatures were similar in both (Table 2). The reduced wind in the intercrop permitted better spread of the mite vector, as we previously observed.

Phytophthora Blight

Epidemiology. Many overcast, rainy days during the 1981 rainy season encouraged severe blight development in the multiple disease nursery. We observed about 50% blight incidence even in lines such as ICP-2376 and BDN 1, which resist the P2 isolate of phytophthora. A *Phytophthora* sp. was isolated and identified as *P. drechsleri* f. sp. *cajani.* Cultural characters and pathogenicity tests on known P2 resistant and susceptible lines show this new isolate is similar to isolate P3 (isolate from Kanpur, northern India). All the lines resistant to isolate P2 were susceptible to the isolate P3. IsolateP3 appears to be common in northern India. We also identified during the 1981 rainy season another isolate from Mhali (Amgaon) in Maharashtra, India that seems to be similar to the P3 isolate. Our observations so far indicate that the P3 type is more widely prevalent than the P2 isolate in India, so we are shifting the priority in our phytophthora program to identify sources of resistance to isolate P3.

Screening for resistance. We screened 476 new germplasm accessions against the P2 isolate and found 14 resistant. The breeding material screened this year included 22 selected lines, 184 early-maturity lines from Hissar, and 188 late-maturity lines from Gwalior. We identified Dwarf-4, BDN 1 (Akola), several lines from a progeny from cross number 74360, 40 Hissar lines, and 37 Gwalior lines as resistant to the P2 isolate. Using germplasm accessions and elite lines found resistant to other diseases, we initiated systematic screening against the P3 isolate. But of 2000 germplasm, 161 elite, and 184 early-maturity lines from Hissar screened, none was resistant.

Fungicidal control. We continued studying the efficacy of metalaxyl for controlling blight in the field. Metalaxyl (Ridomil®) at 1.75 g a.i./kg seed, which had been effective in greenhouse tests, failed to control the blight in a preliminary field test in the 1979/80 season, so we tried higher rates in our 1980/81 and 1981/82 field tests. During 1980/81 metalaxyl, even at 10 g a.i./kg seed, provided no control in the Alfisol and only moderate control (25% blight) in the Vertisol field. But in 1981/82 control was good in our Alfisol field with only 10% blight at 30 days after planting using 7 g a.i./kg seed compared with 49% blight in control plots. By 60 days though, no treatment controlled the disease. Metalaxyl's lack of persistance in pigeonpea plants under field conditions makes it ineffective in controlling phytophthora blight of pigeonpea.

Multiple Disease Resistance

We continued screening breeding material for combined resistance to all three diseases (wilt, sterility mosaic, and phytophthora blight-P2 isolate) in our multiple disease nursery.

Of the 31 germplasm selections screened, only two, 1CP-5097 and -8094, had less than 20% wilt, sterility mosaic, and blight. And of 76 progenies from crosses 73076, 74332, 74360, 74363, and 76009 screened, only one (from cross 74360) seemed to resist all three diseases. The 111 progenies from cross 74360, which resisted wilt and sterility mosaic and were tolerant to blight during the 1980/81 season, were screened, and only 7 showed low disease incidence for all three diseases. None of the nine F_2, F_3, F_4, and F_5 bulks contained plants with promising multiple-disease resistance. All 37 progenies from the three BDN 1 backcrosses screened were susceptible to wilt.

Thus, of 306 breeding lines screened, only 10 showed low multiple-disease incidence, but 331 plants with multiple-disease resistance were selected from 103 breeding lines for rescreening next year in the multiple-disease nursery.

Potentially Serious Diseases

In addition to the three diseases already mentioned, which are the most important in India, four others have destructive potential, particularly in the postrainy-season pigeonpea crop, which is gaining wide acceptance by Indian farmers. The four are alternaria blight *{Alternaria tenuissima,* Fig.3), powdery mildew *(Oidiopsis taurica),* sclerotium blight *(Sclerotium rolfsii),* and yellow mosaic, a whitefly-transmitted virus disease. To identify sources of resistance that breeders may use, we are developing simple techniques to screen for resistance to these diseases.

Figure 3. The value of having a resistant or tolerant variety of pigeonpea when alternaria blight strikes is shown by these contrasting plots in the postrainy season at Varanasi, India. The susceptible variety on the left was severely defoliated by the blight, while the tolerant variety seemed unharmed.

Insect Pests

Surveys

Although our extensive survey of insect pests of pigeonpea throughout India was completed in 1981, we continue to monitor the pests and their damage at selected sites. In the 1981/82 season, *Heliothis armigera* caused substantial losses to farmers' crops, particularly in central and south India. The podfly, *Melanagromyza obtusa,* damaged fields in many areas, particularly in the late-maturing pigeonpea crops in central and northern India. Of the many minor pests, a jassid, *Empoasca kerri,* was unusually common during the crop's vegetative stage in northern India. The hymenopteran pest *Tanaostigmodes* sp. was common and damaging on several of the research stations, where a mixture of cultivars of differing maturities ensures a supply of pods for several months and allows this insect to build up. But on most farmers' fields, it was rare.

One of our entomologists who visited the pigeonpea-growing areas of Kenya and Malawi observed substantial pest damage in most of the fields he surveyed there. The pod borers *Heliothis armigera* and *Maruca testulalis* were generally the most damaging but the sucking bugs *Clavigralla* spp. and *Nezara viridula* were also important. A podfly, *Melanagromyza chalcosoma,* was common in some areas. Although insecticides were used to protect the pigeonpea crops on research stations, few farmers used insecticides. In most areas pigeonpea was intercropped with maize.

Heliothis armigera

Populations. Our surveys have shown that *Heliothis armigera* is the most damaging pest of

Sampling pigeonpea crops for insect pests and their natural enemies continued: an extensive survey throughout India was completed in 1981, and selected sites are still being monitored. This work helps us predict damaging pest populations and identify their natural enemies in time to initiate effective control measures.

pigeonpea throughout the Old World. Its populations vary widely from year to year and from area to area, but they destroy at least 40% of the crop in central and southern India in most years. We are attempting to monitor *Heliothis* populations, hoping to correlate population sizes with climatic and other factors. With such data we should be able to predict damaging populations in time for control measures to be taken on pigeonpea and many other crops that this pest attacks.

We have been recording catches of *Heliothis* moths in light traps at ICRISAT Center since 1974. We have encouraged our colleagues in the national program to set up a network of such traps across India, and we have received data from light traps in 10 locations. Efforts to expand this network have been hampered by operating difficulties. Many sites, where we would like to obtain data, do not have reliable electricity. Also, a skilled recorder is essential to sort, identify, and record the trapped insects, and such skilled assistance is not always available.

Pheromone traps. We have made substantial progress in pheromone trapping of *Heliothis,* and we are cooperating with Dr. B.F. Nesbitt of the Tropical Products Institute, London. We have a synthetic pheromone that is much more attractive than virgin females to male moths. It is a 97:3 mixture of (Z)-11-Hexadecenal: (Z)-9-Hexadecenal which is adsorbed on white rubber septa. A septum loaded with only 1 mg of the pheromone mixture remains attractive to male moths more than 2 months, but we normally change the septa after 28 days.

The traps we use are made from cheap, locally available materials, modified from a design supplied by the Centre for Overseas Pest Research, London. More than 100 male moths are frequently caught in a trap in one night with a record catch, so far, of 288. Very few moths of species other than *Heliothis,* or other insects, enter the traps, so recording is relatively easy.

The light trap network across India has now been supplemented with pheromone traps, and our collaborators are finding pheromone traps much cheaper and easier to operate than light traps. Data are now received from 46 pheromone traps at 26 locations and we hope to extend the network in India and into neighboring countries during 1983.

Pheromone traps modified with locally made materials from a design supplied by the Centre for Overseas Pest Research, London, effectively trap* Heliothis armigera, *the most damaging pest of pigeonpea. Much cheaper and easier to use than light traps, pheromone traps now are being used at 26 locations in India.

The relationship of the catches in two kinds of traps (light and pheromone) to each other, and to populations of eggs and larvae on the host plants in the vicinity, must be determined before the catches can be used to estimate populations. Catches from the two types of trap and estimates of larvae populations on the pesticide-treated areas of ICRISAT Center for 1981/82 (Fig.4) show wide deviations of trap catches from each other and from the estimates of populations of larvae during some periods of the year. We may

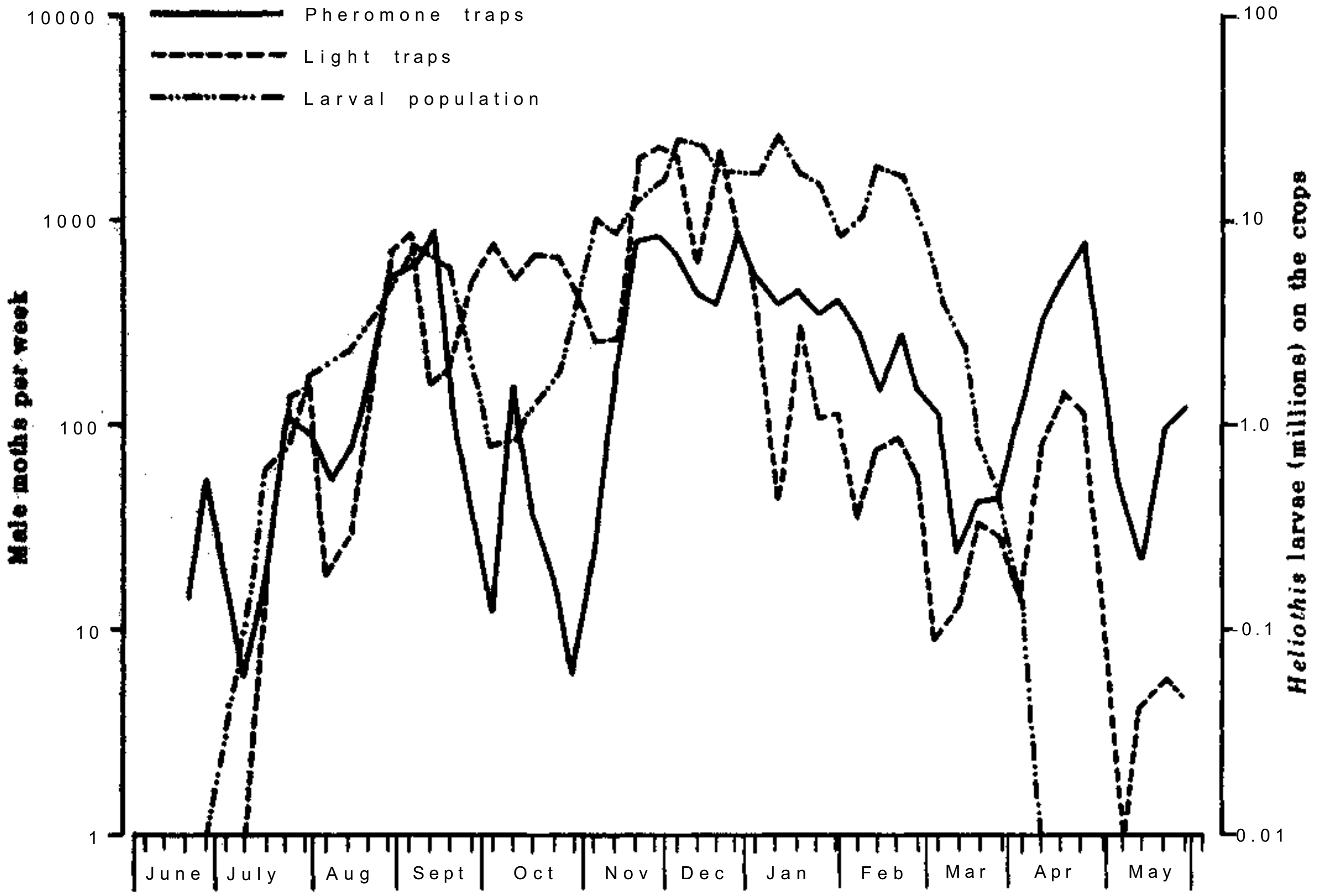


Figure 4. Catches of male moths of *HeUothis armigera* in three light traps and six pheromone traps and larval populations on crops in the pesticide-treated area of ICRISAT Center, 1981/82.

need correction factors, involving climatic and lunar-period variables, before we can use trap data to estimate populations.

Resistance to *Heliothis*. We continued to screen the germplasm and materials generated by our breeders for resistance to *Heliothis* and other pests. Although we have found no plants with strong resistance, we have found considerable differences in susceptibility to the pests. Breeders are crossing several of our selections in attempts to intensify the resistance. Progenies from their crosses will be screened during the next 2 years. An example of the range of susceptibilities already available in our late-maturing materials is shown in Table 3. The percentages of bored pods, mainly from *HeUothis* feeding, ranged from 19.4 in a commonly used, relatively resistant cultivar to 46.4 in a susceptible selection. The coefficients of variation for pest damage were high; such variability gives us problems in screening.

We are investigating the mechanisms involved in different levels of susceptibility in our selections in cooperation with biochemists from ICRISAT and from the Max-Planck Institute for Biochemistry at Munich, Germany. Although this work is in a preliminary stage, there appear to be differences in pod-wall exudates of some of our selections. The differences are being detected with a high-performance liquid chromatograph donated to ICRISAT for this purpose by the German Agency for Technical Cooperation (GTZ).

Biological control. Monitoring of natural enemies *of HeUothis* on pigeonpea and other crops continued with increased attention to *HeUothis* predators. Among its known predators on pigeonpea, spiders, ants, coccinelids, and chrysopids are all fairly common. We monitor their populations by a variety of methods, including sweep nets, pitfall traps, and sticky boards.

The commonest spiders of pigeonpea at ICRISAT Center appear to be *Clubiona* sp and *Thomisus* sp. In laboratory feeding trials, *Clubiona* sp consumed an average of 59.3 ±9.17 *Heliothis* eggs and 3.2 ± 0.28 second instar *Heliothis larvae* per spider per day, over several days of tests. Those spiders and other predators may considerably reduce populations of *Heliothis* eggs and larvae on the pigeonpea crops, but quantifying the reduction is difficult.

Table 3. Pod damage in pesticide-free area from a 3-replication RBD trial of late-maturing pigeonpeas selected for differing susceptibilities to pests in previous years, ICRISAT, 1981-82.

Selection	Characters[1] selected for in previous years	% of pods damaged by	
		Borers	Podfly
ICP-8102-5-S1	MB, LPf	45.9	11.9
NP(WR)-I5	LB	19.4	22.4
ICP-8094-2-S2	LB, HPf	19.7	20.4
ICP-5651-1-S3	LB, HPf	33.7	40.0
ICP-7194-1-S4	LPf	33.1	16.4
GW-3 (Check)	-	31.2	32.4
ICP-8606-E1	HPf	28.6	33.6
ICP-7041-E1	MB	27.9	25.0
ICP-8127-E1	LB, HPf	22.0	37.9
ICP-8130-E1	HPf	21.3	32.9
ICP-8571-E1	MB, HPf	23.4	29.4
1CP-8583-E1	LB	33.0	26.6
1CP-7537-E1	LB	22.8	32.0
ICP-4640-E1	LB	35.4	31.7
PPE-38-2	LB, HPf	23.4	28.1
ICP-4745-2-E8	LB	24.6	21.0
PPE-36-2	LB, HPf	29.9	26.9
PPE-38-1	LB, HPf	28.6	30.4
1CP-7176-18-E2	LPf	28.9	22.3
1CP-7496-E1	LB	26.6	22.7
ICP-7176-5-E1	HB, LPf	46.4	10.6
ICP-8134-1-S1	LPf	23.6	27.2
ICP-2114-E1	LB	28.8	23.5
ICP-7337-2-S4	HPf	43.0	45.8
SE		±4.85	±5.01
CV (%)		30.6	33.7

1. LB = low borer infestation; MB = moderate borer infestations; HB = high borer infestation; LPf = low podfly infestation; HPf = high podfly infestation.

We continued to rear and field release at ICRISAT Center *Eucelatoria bryani,* a tachinid parasite of *Heliothis* imported from the USA. It has been reported to breed well only at temperatures below 30°C and reproduction has been poor at 35°C. Maximum temperatures at ICRISAT Center, and throughout much of central and southern India, exceed 35°C for lengthy periods every year so this parasite may not survive in our fields. In incubator tests, it breeds well under a 35°C day, 30°C night regime, so we will select for tolerance to higher temperatures by exposing successive generations to increasing temperatures. We also hope to improve the genetic diversity of our culture by incorporating fresh imports into our stock.

Eggs of *H. armigera* collected from many host-plant species are usually heavily parasitized. On sorghum, for example, we frequently find more than 50% of the eggs parasitized by *Trichogramma* sp. But few (< 1 %) *Heliothis* eggs on pigeonpea are parasitized. In cooperation with the National Centre for Biological Control, Bangalore, and the Central Biological Control Station, Hyderabad, we are now testing a range of *Trichogramma* spp to determine whether any will parasitize *Heliothis* eggs on pigeonpea.

Insecticide use. Although yield increases exceeding 100% can be obtained by using insecticides on pigeonpea, particularly on the early- and mid-maturity cultivars that form pods during the peak *Heliothis* attacks, our surveys show that less than 10% of farmers use insecticides on this crop. Difficulty of spraying the tall, dense crop with available sprayers and the recommended 600 liters per hectare of water for the spray mix are obstacles to fanners. Such obstacles may be largely overcome by controlled droplet applicators (CDA) at ultra low volume.

Controlled droplet applicators make spraying tall pigeonpea crops easier and more effective. At ICRISAT Center, proper spraying reduced **Heliothis** *populations and increased yields 40% over plots sprayed with hand-operated knapsacks.*

In the past year we compared the conventional hand-operated knapsack sprayers, motorized knapsack sprayers, and battery-operated spinning-disc CDA sprayers. With a single application of endosulfan at 0.7 kg of a.i/ha sprayed at the peak of pest attack, more *Heliothis* were killed in plots sprayed by the CDA sprayers than in those sprayed conventionally (Table 4), but a single spray did not fully protect the crop. Yields were low, largely because of severe *Heliothis* attack, but yields from the CDA-sprayed plots were 40% greater than from plots sprayed with hand-operated knapsacks.

Spinning disc CDA sprayers are now fairly widely available in India but suitable formulations of insecticides are not yet available. Such formulations should be of low volatility and nonphytotoxic when high concentrations are sprayed at low volume.

Podfly

Populations. The podfly, *Melanagromyza obtusa,* is the second most damaging pest of pigeonpea in India. Found in all areas, it is commonest in the central and northern states where it regularly reduces yields 20% or more. In southern India it is much less important than *Heliothis* in early- and mid-maturing cultivars. When *Heliothis* destroys the early crop, the compensatory flush of pods is often severely infested with podfly.

As in previous years we monitored the incidence of podfly by opening samples of pods at regular intervals. We have yet to discover a way to monitor the adults with any form of trapping. As we have found no podfly resting stage, we assume that it bridges the summer and monsoon period by feeding in wild legume pods. Our studies of alternative hosts showed *Flemingia* sp. with 75% of its pods damaged by podflies.

Resistance to podfly. Our search for resistance to podfly continued with screening germplasm and new materials supplied by our breeders. As podfly is most damaging in late-maturing pigeonpeas, we concentrate on that maturity

Table 4. Pod damage assessments of pigeonpea cv ICP-1 sprayed with endosulfan at 0.7 kg a.i./ha by conventional and CDA sprayers, ICRISAT Center, 1981/82.

	Volume of spray mix applied (1/ha)	Mean pod damage (%)	
		Borers	Podfly
Knapsack sprayer (hand operated)	500	60	37
Knapsack sprayer (motorized)	250	51	53
CDA sprayer	4	32	34
SE		±9.7	±0.8
CV (%)		28.8	2.6

group. Data in Table 3 show the range of susceptibility in our late-maturing selections. Podfly damage ranged from 10.6% in material selected as relatively resistant to podfly to 45.8% in a highly susceptible selection. The selections most resistant to podfly are susceptible to *Heliothis.*

Several selections showing reduced susceptibility to podfly are now in our breeders' crossing program. They made 86 crosses with the material this year to introduce insect resistance and short-plant stature for easy spraying.

To assess some of our most advanced breeding lines under natural insect pressure, we planted 24 lines in a yield test in our pesticide-free area. Under heavy insect attacks, yields of four of the lines exceeded 900 kg/ha, more than twice as much as the check (cv C 11).

As in previous years we found that washing the racemes of some cultivars with water increased their susceptibility to podfly. Differences in infestation were greater between pods from washed and unwashed whole plants than between pods from washed and unwashed racemes on the same plant. In cooperation with the biochemists, we are studying water-soluble exudates of pod walls.

Natural enemies. Previous reports refer only to *Euderus* sp as a parasite of podfly, but we have discovered three more parasites: *Eurytoma* sp, *Ormyrus* sp, and *Antistrophoplex* sp. One or more of them may be hyperparasites.

In cooperation with the entomologists of the All India Coordinated Pulse Improvement Project, we surveyed parasitism in podfly from 11 states in India. Cooperators sent samples of pods, we counted podfly larvae and pupae in the pods and then observed these for emergence of parasites. Table 5 shows that parasitism was generally below 10%, and that *Euderus* sp was the commonest parasite.

Insecticide use. Although endosulfan is recommended to control podfly infestations in some areas of India, it has not controlled the pest on our ICRISAT Center farm. So we tested a range of insecticides on the developing stages and adults of podfly in both laboratory and field. Dimethoate was more effective than endosulfan, monocrotophos, or DDT, against both adults and larvae inside pods. Cypermethrin, a synthetic pyrethroid that is particularly effective against *Heliothis,* gave reasonable control of

Table 5. Summary of data from samples of pigeonpea pods (collected from indicated states of India) examined for incidence of podfly and its parasites, 1981/82.

State	Pods examined	Podfly larvae and pupae found (no.)	Parasitized (%)	Dominant parasite[1]
Andhra Pradesh	745	260	9.6	E
Bihar	833	229	9.6	O
Gujarat	859	671	7.7	E
Haryana	2476	452	13.9	E
Karnataka	1431	348	6.9	E
Madhya Pradesh	6834	3353	10.4	E
Maharashtra	1264	151	12.6	E
Orissa	701	307	0.7	E
Rajasthan	1846	597	1.0	-
Uttar Pradesh	5826	2543	6.1	E
West Bengal	1013	380	3.7	E

1. E = *Euderus* sp; O = *Ormyrus* ap (equal numbers of *Eurytoma* sp, *Ormyrus* sp, and *Antistrophoplex sp* were found in Rajasthan).

podfly adults but little or no control of larvae inside the pods.

Biological Nitrogen Fixation

Rhizobium Culture Collection

We continued to fill requests from several countries for strains from our pigeonpea *Rhizobium* culture collection. We have initiated studies on the specificity of the strains in relation to *Atylosia* and *Rhynchosia,* genera that are closely related to *Cajanus* and that may be useful in the breeding program.

Rhizobium Inoculation Under Low Inputs

In farmers' fields. Farmers' fields in the semi-arid tropics are generally low in plant nutrients. Pigeonpea is grown under rainfed conditions with a minimum of inputs. Surveys have revealed that pigeonpea nodulates poorly under those conditions, so we conducted simple *Rhizobium* inoculation trials on five farmers' fields in Aurepalle village, 60 km south of Hyderabad, to see if inoculation alone would improve nodulation and nitrogen fixation. The farmers did the sowing under our supervision; otherwise the trials did not affect the farmers' routine field operations, which were to grow pigeonpeas as an intercrop with sorghum or pearl millet.

Thirty days after planting neither nodulation nor nitrogenase activity differed significantly between inoculated and noninoculated plants (Table 6). Waterlogging and pests ruined three fields so yields were measured in only two fields. In these two fields yields were extremely low and there was no response to *Rhizobium* inoculation.

In pesticide-free areas at ICRISAT. At ICRISAT we maintain a pesticide-free, low-nutrient input area to simulate SAT farmers' field conditions. Simple inoculation experiments were laid

Table 6. Effects of inoculation on nodulation and nitrogen-fixation in pigeonpea grown with low inputs on five farmers' fields in Aurepalle, A.P., India, rainy season 1981.

		30 days after sowing					At maturity	
				Nitrogenase activity (μM C_2H_4 produced/hr)				
Farmer	Treatment	Nodule / plant (no.)	Nodule dwt/plant (mg)	Per plant	Per g dwt of nodules	Top dry wt/ plant (mg)	Grain yield (kg/ha)	Total dry matter (kg/ha)
A	Inoculated	8.5	8.0	0.08	2.0	320	155	1023
	Not inoculated	8.0	8.5	0.16	13.4	290	157	1088
B	Inoculated	5.8	22.0	0.01	4.3	640	0	315
	Not inoculated	5.9	20.0	0.03	11.6	610	0	446
C	Inoculated	12.3	7.5	0.72	83.0	270	ND[a]	ND
	Not inoculated	9.1	4.9	0.37	57.1	210	ND	ND
D	Inoculated	4.0	3.0	0.09	22.5	460	ND	ND
	Not inoculated	4.0	1.7	0.04	18.1	400	ND	ND
E	Inoculated	6.0	4.0	0.04	24.8	620	ND	ND
	Not inoculated	4.0	1.8	0.01	4.8	620	ND	ND

a. ND = Not determined.

Table 7. Effect of *Rhizobium* inoculation on nitrogenase activity, nodulation, and plant dry matter SO days after planting, and final yields at maturity in pigeonpea grown at three low-input sites, ICRISAT Center, 1981.

		50 days after planting					At maturity		
		Nitrogenase activity							
Field	Treatment	μM C_2H_4/ plant per hr	μM C_2H_4/g dry nodule per hr	Nodule/ plant (no.)	Nodule dry wt/ plant (mg)	Top dry matter/ plant (g)	Fallen plant parts	Grain wt. (kg/ha)	Total dry matter
Vertisol 1	Inoculated	1.6	112	5.2	13	4.8	2600	940	6550
	Not inoculated	1.4	68	5.4	20	4.9	2550	680	5900
	SE ±	0.44	16.6	1.3	3.1	0.17	132	105	230
	CV (%)	88	55	73	56	11	15	34	13
Vertisol 2	Inoculated	2.4	112	9.0	20	6.4	2670	680	5540
	Not inoculated	2.6	97	8.5	30	6.6	2860	640	5940
	SE ±	0.53	8.2	1.12	10	0.23	111	61	223
	CV (%)	67	25	40	66	11	13	20	12
Alfisol	Inoculated	12.8	159	16	80	4.0	1840	1050	4240
	Not inoculated	13.7	171	18	83	3.8	1680	920	3760
	SE ±	1.93	12.0	1.8	10.4	0.28	116	53	246
	CV (%)	46	23	34	40	23	21	17	20

out on three fields in that area, two on Vertisols and one on Alfisol, to measure pigeonpea's response to *Rhizobium* inoculation. The initial population was 10^4 to 10^5 rhizobia/g dry soil. Samples taken around 50 days after planting showed no response to inoculation in nodulation, nitrogenase activity, or plant dry matter (Table 7). The first flush of pods was completely damaged by *Heliothis armigera;* damage was less on subsequently formed pods. Fallen plant parts, collected fortnightly until final harvest, were pooled and weighed. Data on fallen plant parts, final grain yield, and total dry matter showed no significant differences between inoculated and noninoculated plots (Table 7).

There may be several reasons for the low yields on farmers' fields relative to those in ICRISAT's pesticide-free area. An intercrop of pigeonpea, like that on farmers' fields, generally yields less than a sole crop, as grown on the ICRISAT farm. Only one flush of pods was collected in the farmers' fields, while three flushes were collected in our fields. Our soils, like theirs, were low in nutrients, particularly in available nitrogen and phosphorus (Table 8). That lack of response to inoculation might stem from lack of other nutrients necessary for nodulation. Nitrogen fixation is being examined in studies at Aurepalle and ICRISAT.

Residual effect of pigeonpea. Pigeonpea, grown as a sole crop, has a large beneficial effect on the next crop (maize) (ICRISAT Annual Report 1981, pp 133-136). This has been attributed partly to fallen leaf parts. To examine that hypothesis, we maintained plots with fallen plant parts plowed in situ after harvest and others with fallen plant parts removed and discarded. We shall plant maize on the plots next year.

Table 8. Chemical properties of the soil from two farmers' fields and unsprayed areas at ICRISAT Center taken at beginning of the 1981 rainy season when inoculation trials were sown.

Field	PH	E.C (m mhos/ cm)	Total N (%)	NH_4-N (ppm)	NO_3-N (ppm)	Organic carbon (%)	Olsen's available 'P (ppm)
At Aurepalle[1]							
Farmer 'E'	8.4	0.15	.049	8	2	0.34	4.0
Farmer 'A'	8.6	0.15	.031	6	3	0.43	18.5
At ICRISAT[2]							
Vertisol 1	8.0	0.17	.049	10	3	0.40	2.5
Vertisol 2	8.2	0.19	.041	11	3	0.32	3.0
Alfisol	7.2	0.15	.034	14	2	0.23	3.0

1. 0- to 30-cm soil profile.
2. 0- to 15-cm soil profile.

^{15}N for Measuring Nitrogen Fixation

During the 1980 µrainy season, we conducted a field experiment in collaboration with the International Atomic Energy Agency, Vienna, to measure the nitrogen fixed by pigeonpea grown in an Alfisol compared with castor bean *(Ricinus communis)* as a nonfixing crop. N_2-fixation was to be measured by the isotope ^{15}N dilution method and 'A' value. Two pigeonpea cultivars were grown at 0 and 20 kg N/ha; castor bean, at 0, 20, and 100 kg N/ha applied as ^{15}N-labeled ammonium sulphate. Though the crops germinated well, a prolonged drought limited pigeonpea nodulation and acetylene reduction activity as a measure of nitrogen fixation. Grain and total dry-matter yields of both pigeonpea and castor were low, so we did not measure N_2-fixation. Despite the poor growth and yields, castor appears to be a good nonfixing control crop in this environment because it survives under drought stress and its growth period is similar to that of pigeonpea.

Another experiment with ^{15}N was conducted in the 1981 rainy season to measure N_2-fixation by pigeonpea in a Vertisol field and to assess N_2-fixation lost by pigeonpea to the nodule-eating insect, *Rivellia angulata* (ICRISAT Annual Reports 1976/77 and 1978/79). Weused aldrin at 2 kg a.i./ha to control the nodule-eating insect. Because castor is sensitive to waterlogging, which is associated with Vertisol fields, we used a long-duration sorghum cultivar (IS 19747) as the nonfixing control crop. The soil N pool was labeled with ^{15}N-labeled ammonium sulphate at 20 kg N/ha in both aldrin-treated and control plots. To examine carbofuran's effect in controlling nodule damage and providing protection against other insects, we used 1.2 kg/ha of it on plots where no ^{15}N was applied. Forty-seven days after the plots were planted both insecticide applications had reduced nodule damage and increased nitrogenase activity and dry-matter production (Table 9), but differences disappeared in later samplings. To determine total N and ^{15}N we harvested both crop species at the same time. Pigeonpea was still at the late podding stage but sorghum had matured.

The isotope-dilution method indicated that 86.3% of the nitrogen in the plant tops (= 66.5 kg N/ha) was derived from biological nitrogen fixation in the insecticide-free plots (Table 10). The accuracy of that determination depends on both the pigeonpea and sorghum exploring the same volume of soil at the same rate. But sorghum probably explored the soil faster because it grew more rapidly than pigeonpea and took up more

Table 9. Effect of carbofuran and aldrin on insect-caused nodule damage and nitrogenase activity in 47-day-old pigeonpea plants grown on a Vertisol field at ICR1SAT Center, rainy season 1981.

Treatment	Nodule/ plant (no.)	Nodules damaged (%)	Nodule dry wt/ plant (mg)	Nitrogenase activity: μM C_2H_4/ plant per hr	Nitrogenase activity: μM C_2H_4/ g dry nodules per hr	Top dry wt/ plant (g)
Carbofuran	8	19	33	4.6	129	3.6
Aldrin	16	40	39	4.1	100	3.7
Control	15	63	24	1.8	68	3.0
SE ±	2.7	7.2	7.3	1.5	17.9	0.12
CV (%)	36	31	39	75	31	6

nitrogen and ^{15}N. So sorghum is not a suitable nonfixing control for mid-duration pigeonpea. Also aldrin adversely affected sorghum growth and N uptake but did not significantly affect ^{15}N uptake. So N fixed by pigeonpea in the presence of aldrin may be even further overestimated.

Because we have no nonnodulating pigeonpea as a control, we are investigating techniques in the field to ensure that both legume and reference crops explore the same volume of soil to which ^{15}N has been applied.

Ureides as a Measure of Nitrogen Fixation

Ureides in pigeonpea xylem sap and their relationships with nodulation and nitrogenase activity have been reported previously (ICRISAT Annual Report 1979/80). The distribution of ureides in different plant tissues has been studied to determine whether tissue analysis, which would provide simple, nondestructive sampling, could be used as an alternative to sap analysis, which destroys whole plants. We used the approach on both well-nodulated plants and plants grown with nitrogen fertilizer added, sampling the plants at 10-day intervals to 100 days. Ureides were most abundant in the shoot tip but changes in their concentration there bore little relation to the ureides in the sap or to nodulation and N_2-fixation.

Chemical studies continue on the relationship of ureides to other nitrogen components in the sap. The possibility of using total reduced nitro-

Table 10. Effect of aldrin on yields, ^{15}N uptake by pigeonpea cv ICP-1 and sorghum, and nitrogen-fixation by pigeonpea grown at ICRISAT Center, rainy season 1981.

Treatments	Total dry matter (kg/ha)		N in dry matter (kg/ha)		^{15}N atom excess (%)		N_2-fixation by pigeonpea	
	PP[1]	S[2]	PP	S	PP	S	(%)[3]	kg/ha
Aldrin	5540	11600	78	67	.022	.200	88.8	69
Control	5620	17530	77	92	.021	.153	86.3	66
SE ±	510	1860	4.5	10.3	.0051	.0306	3.0	3.9
CV (%)	16	22	10	22	41	30	6	10

1. PP - pigeonpea at late podding.
2. S - sorghum (nonfixing control) at full maturity.
3. Perentage of nitrogen derived from fixation.

gen in the sap to measure N_2-fixation is governed by the presence in the roots of nitrate reductase. This is being studied in pot experiments using ^{15}N fertilizer to determine whether nitrate is reduced in the root.

Selecting Pigeonpea for Nitrogen Fixation

Considerable effort has been directed to screening pigeonpea germplasm to identify lines with superior nodulation and nitrogen fixation. While lines differ, intraline variation has been particularly wide. The variation may stem from the considerable amount of outcrossing that occurs in this species. For this study we selected advanced breeders' lines of different maturities that had been selfed two to four times. They were grown in pots and examined after 35 days, when well and poorly nodulated plants were selected for further selfing. Selection was based on a careful nodule count before the plants were repotted for seed production. Plant grown from this seed will be further selected, advanced by selfing, and used in attempts to increase nodulation and decrease plant-to-plant variability so evident in pigeonpeas.

Physical Environment

Yield Potential

Yields of medium-duration pigeonpea cultivars, which are adapted to peninsular India, generally average less than 1500 kg/ha and rarely exceed 2000 kg/ha at ICRISAT Center, Patancheru. The plasticity of this group of cultivars apparently keeps them from responding to increasing plant density (ICRISAT Annual Report 1979/80, pp. 106-107).

To determine the potential yield of pigeonpea grown with minimal stress in Vertisol and Alfisol, we used five medium-maturity cultivars in large plots with high fertilizer input, frequent irrigation, and intensive plant protection.

The highest yield was 2300 kg/ha for ICP-1-6 on Vertisol (Table 11). Total dry matter was similar on the two soil types, but grain yielded more on Vertisol, so harvest indices were higher on Vertisol.

In a similar large plot trial at our Hissar station, early-maturity pigeonpea cultivars yielded more in a shorter time (Table 12) than the medium-maturity cultivars at ICRISAT Center (Table 11).

Table 11. Growth duration, total dry matter, and yield of medium-maturity pigeonpea cultivars in Vertisol (V) and Alfisol (A) with high inputs, ICRISAT Center, 1981.

Cultivar	Soil type	Crop growth duration (days)	Total dry matter (kg/ha)	Grain yield (kg/ha)
ICP-1-6	V	200	10340± 460	2305± 20.8
	A	193	11130 + 1128	I185± 43.1
ICPL-270	V	192	7716+ 272	1967 ± 28.9
	A	187	7753± 578	1484 ± 61.1
ICPH-6	V	192	8799± 287	2015 ± 44.8
	A	191	6896± 854	1312 + 65.2
C 11	V	187	9569+ 353	1952± 37.8
	A	187	7558± 479	1394 + 104.0
BDN 1	V	184	6999± 154	1897 + 43.6
	A	181	8760± 639	1855 + 53.3

Table 12. Growth duration, total dry matter, and yield of extra-early pigeonpea cultivars grown with high inputs, ICRISAT station, Hissar, India, 1981.

Cultivar	Habit	Crop growth duration (days)	Total dry matter (kg/ha)	Grain yield (kg/ha)
ICPL-81	NDT	115	8365	2231
ICPL-1	NDT	136	8658	2670
UPAS 120	NDT	150	11881	2267
1CPL-87	DT	143	11673	3419
ICPL-267	DT	98	NR[2]	2047
ICPL-179	DT	99	NR	1468

1. NDT = nondeterminate; DT = determinate.
2. NR = not recorded.

Higher yields at Hissar than at Patancheru are of considerable interest. During the monsoon season, June to September, mean temperature is about *5°C* higher at Hissar than at Patancheru. And early cultivars at Hissar mature before cold winter weather, while medium-maturing cultivars at Patancheru mature during November and December. So a major reason for higher yields at Hissar may be the plants developing under warmer temperatures.

Climate and Growth

To examine the effects of temperature and other environmental factors on crop growth rates, we sowed four cultivars of pigeonpea, UPAS 120 (extra early), T 21 (early), C 11 (medium), and NP(WR)-15 (late) at monthly intervals from April to February at ICRISAT Center. The plants were irrigated frequently to minimize drought stress, and crop growth rate was determined over the first 50 days after seeding, during the vegetative phase.

Growth rates of cultivars differed significantly, with cv UPAS 120 the slowest. All cultivars, however, showed similar responses to sowing date, with most growth in April and May plantings, and least in November and December (Fig.5). Both solar radiation and high temperature may have contributed to the high growth rates in the April and May plantings, while the greatly reduced growth in the winter season may have stemmed mainly from low temperatures. Plants sown in June, for example, had a growth rate six times higher than plants sown in November. Mean solar radiation throughout the growing season was less in the June sowing (owing to cloudy weather), but the mean temperature was 6°C and the minimum temperature was 9.5°C higher than in the November sowing. We are carrying out further studies of temperature effects on vegetative and reproductive growth.

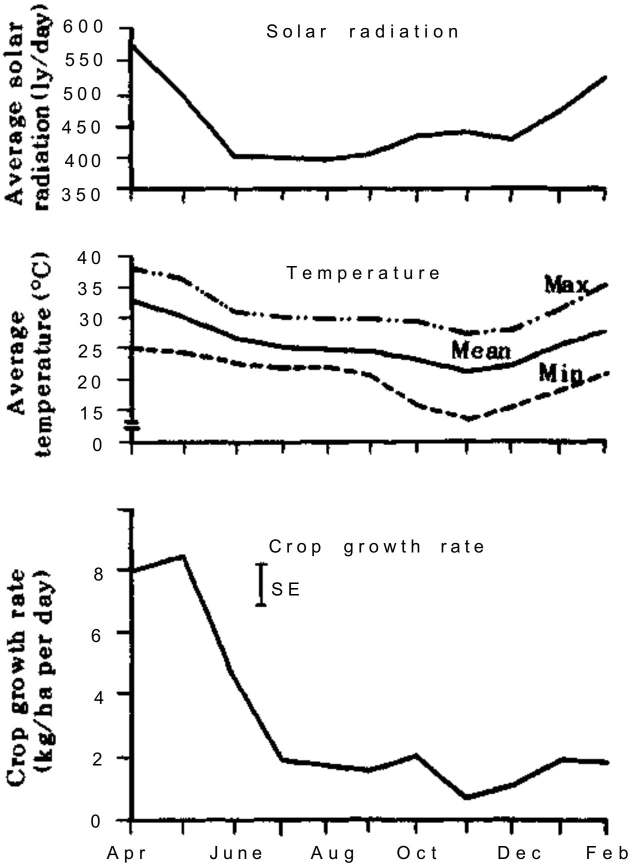


Figure 5. Mean growth rates of 4 pigeonpea cultivars the first 50 days after sowing, with different dates of planting, ICRISAT Center, 1981/82. Average solar radiation; maximum, mean, and minimum temperatures for the same 50-day periods are shown. (Mean temperatures represent the means at hourly intervals each day).

Effects of Soil Cracking

Last year we reported second harvest yields of pigeonpea consistently higher in Alfisols than in Vertisols even though Vertisols' water-holding capacity is greater (ICRISAT Annual Report 1981, p. 138). Vertisols characteristically develop deep cracks as the postrainy season advances. The cracks increase evaporative water losses from the soil and damage roots as the soil pulls apart. The cracking may reduce yields of both the second harvest and the first harvest of the rainy-season crop, which normally sets seed at ICRISAT Center well after the rains cease.

Different land management practices, like broadbeds, ridges and furrows and flat planting, have different influences on how cracks develop.

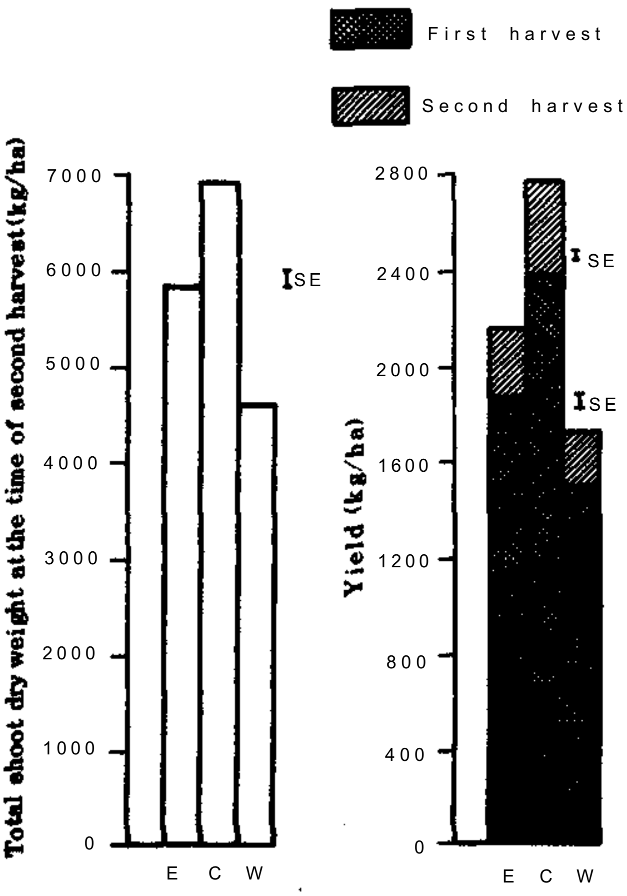


Figure 6. Total dry weight, and yields of first and second harvests of pigeonpea cv C 11 in east (E) central (C) and west (W) rows on broadbeds on a Vertisol at ICRISAT Center, 1981/82.

In the broadbed system, cracks predominantly develop from wheel pressure of the bullock-drawn Tropicultor in the furrow. To test the effect of soil cracking on yield, we sowed three rows of pigeonpea 50 cm apart on broadbeds running north and south, so we had a row in the middle of the bed and an eastern and a western row on the outside of the bed. The two outside rows were closer to the cracks that developed in the furrows so we expected them to yield less.

As expected, grain yield and total dry matter in both the first and second harvests were significantly higher in the central row than in border rows (Fig.6). Mulches in the furrows to reduce or stop evaporative loss of water had no significant effect.

A curious feature of our results was that the eastern rows yielded significantly more than the western rows. Last year we found a similar difference from east and west rows on the sides of north-south 75-cm ridges. Since cracking intensity is similar in each furrow, yield differences may have resulted from asymmetrical root growth, perhaps as a consequence of the south-west monsoon winds prevailing while the plants were young. An east-west asymmetry of the root system would mean that roots on the east side would be damaged less than roots on the west side of each bed or ridge. We are investigating that possibility.

A Perennial Pigeonpea Cropping System

Pigeonpea as a postrainy-season crop on deep Vertisols is now well established in areas where temperatures are high enough for good growth. We have tried a cropping method that extends the cropping time of postrainy-season pigeonpeas to three crops (Fig.7). The normal postrainy-season crop, seeded in September or October, is harvested by ratooning in late February or March. The ratooned plants remain in the field and, because of their deep root system and perennial nature, most survive. With the onset of monsoon rains they quickly establish a full canopy, so the second crop develops with no addi-

Table 13. Three-harvest yields of pigeonpea cv ICP-1-6 planted 11 November 1980 at Sangareddy, A.P., India.

	Seed yield (kg/ha)			
Method of first harvest	First harvest 26.3.1981	Second harvest 19.12.1981[a]	Third harvest 6.4.1982	Total
Pod picking (nonratooned)	352	1449	131	1932
Ratooning at 30 cm plant height	400	1437	110	1947
Ratooning at 10 cm plant height	423	1214	113	1750
SE ±	33.0	101.0	11.8	
Mean	390	1370	120	1880
CV (%)	16.8	15.0	27.0	

a. Harvested at 150 cm plant height.

tional expenses for land preparation or planting and it can be harvested in December. After a third harvest from the same plants in March or April, the crop is removed. This triple-harvest system has a great potential for the extensive Vertisol areas in India, which normally are left fallow during the rainy season.

By planting a postrainy-season crop with cv ICP-1-6 that is both wilt-resistant and sterility mosaic tolerant, we demonstrated that the system is feasible. A cultivar with resistance or tolerance to both of those diseases appears essential for the system to succeed. On earlier attempts with a susceptible cultivar we lost the third crop before harvest. First yields of the postrainy-season crop this year were low (390 kg/ha) (Table 13) probably because it was planted in November instead of September or October. But

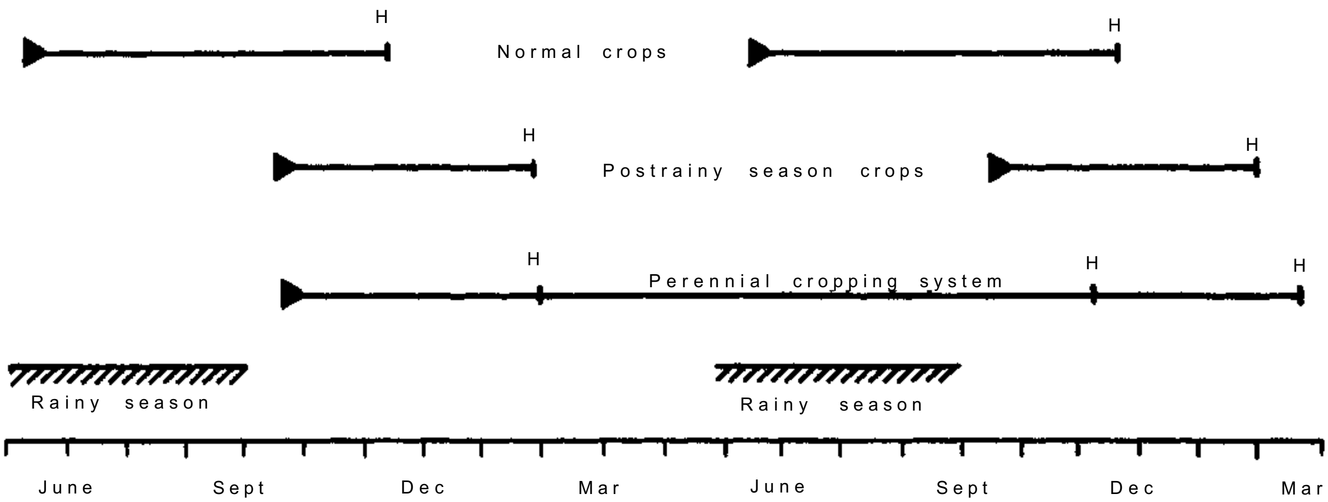


Figure 7. Diagrammatic representation of the perennial pigeonpea cropping system starting in the postrainy season, compared with the normal and postrainy season annual cropping systems with medium maturity cultivars. H = harvest time.

In the management system that produces three pigeonpea crops from one planting, the first harvest is by ratooning, with the ratooned stubble left to quickly establish a full canopy when the monsoon arrives. Considerable firewood may be removed (below) after the third harvest.

the yield the following December was 1370 kg/ha, which is comparable to that of a crop planted at the beginning of the rainy season. The yield of the third ratoon crop, harvested in April, was low (120 kg/ha), but again comparable to the second harvest normally obtained from a rainy-season crop on Vertisol (ICRISAT Annual Report 1981, p. 138). Besides the seed yield, substantial quantities of firewood were produced, and fallen leaves returned about 40 kg/ha of nitrogen to the soil. We are further examining the system.

Planting Date and Population

Our experience has been that early-maturity genotypes respond to higher-than-normal seeding rates (ICRISAT Annual Report 1977/78, Table 52, p. 100). So we used two determinate advanced lines, ICPL-267 and ICPL-87, and two indeterminate ones, ICPL-81 and ICPL-142, at Hissar, sown 26 June and 21 July 1981, at six population densities ranging from 5.5 to 133 plants/m^2. The June planting gave higher yields at all the six populations than the July planting (Table 14). The densest populations gave the highest yields in June plantings except that ICPL-142, an indeterminate line, yielded best at 22 plants/m^2. The profuse growth of the June planting may be why ICPL-142 used the wider spacing more effectively than the other shorter, more upright lines. All the lines in the July planting yielded best at high population densities, which indicates that many cultivars may continue to give increased yields when seeded at more than a million plants per hectare. Various cultivars seeded densely, however, may respond differently to planting date.

Grain and Food Quality

Cooking Quality

The cooking qualities of 18 pigeonpea cultivars, each grown during both the rainy and postrainy season of 1981/82 at ICRISAT Center, were evaluated. Analysis of the data indicated that the same cultivar grown during the postrainy season requires longer to cook than when grown during the rainy season. Organoleptic qualities such as color, taste, flavor, and texture were evaluated on cooked dhal samples by five taste panelists. None of those factors differed significantly among the 18 cultivars grown in either season. In 6 of the 18 cultivars, red or white testa had no bearing on organoleptic qualities of dhal samples (Table 15), which differs from our village-

Table 14. Effects of date of planting and plant population on yield (kg/ha) of four experimental early pigeonpea lines, ICRISAT Station, Hissar, rainy season 1981.

Spacing	Population	ICPL-267		ICPL-87		ICPL-81		ICPL-142		Mean	
(cm)	(plants/m^2)	26 June	21 July	26 June	21 July	26 June	21 July	26 June	21 July	26 June	21 July
30 x 2.5	133	1960	2230	2730	2210	2950	1990	1760	1580	2350	2200
30 x 5	66	1720	2210	2590	1930	2610	2170	2160	1690	2270	2000
30 x 10	33	1690	1790	2640	1920	2570	1960	2180	1680	2270	1840
30 x 15	22	1620	1870	2490	1970	2420	1810	2290	1610	2200	1820
30 x 30	11	1230	1580	2410	1790	2100	1750	2050	1650	1950	1690
30 x 60	5.5	910	1440	1910	1510	1700	1560	2030	1380	1640	1470
Mean		1520	1860	2460	1890	2390	1870	2080	1860		
SE		For population within cultivar ±88									
		For cultivar within planting date ±54									
		For planting date for each cultivar ±74									

Table 15. Organoleptic qualities[1] of cooked dhal sampeles prepared from pigeonpea cultivars with indicated testa color.

Testa color	Cultivar	Color	Taste	Flavor	Texture	General acceptability
Red	No. 148	2.8	2.8	3.0	3.0	3.0
	C 11	3.0	2.4	2.2	2.8	2.4
	BDN 1	3.0	2.4	2.8	2.2	2.4
White	Hy 8	2.2	2.2	2.6	2.6	2.4
	BDN 2	3.0	2.6	3.0	3.0	3.0
	GS-2	3.0	2.4	2.8	2.2	2.4
	Mean	2.8	2.4	2.7	2.6	2.6

1. Good = 3; fair = 2; poor = 1. Average of 2 replicates by 5 panel members.

level survey where consumers preferred red pigeonpeas to white ones.

To examine further the cooking-quality variability among pigeonpea lines, we analyzed 140 germplasm accessions for cooking time, water absorption, percentage of solids dispersed, and instron-force hardness. Cooking time ranged from 18 to 60 minutes with a mean of 25.3. Microscopic examination of starch granules from one accession each of low (18 min), medium (43 min), and high (60 min) cooking time indicated that size and shape of starch granules had no relationship to cooking time. Neither did cooking times differ widely between dhal made from pigeonpea cv C 11 and kept in a polythene container with an insecticide-impregnated strip and stored 12 months, and dhal freshly prepared from whole-seed samples stored the same way for 12 months.

We found no clear-cut differences in cooking quality when we evaluated six pigeonpea cultivars belonging to early-, eight to medium-, and eight to late-maturity groups, which confirms our earlier observations. And cooking-quality characteristics of five pigeonpea cultivars, each grown on both Vertisols and Alfisols, were similar.

Protein Quality

Protein contents of 1358 breeding lines we analyzed ranged from 15.5 to 25.2%. In addition, we used the standardized rapid colorimetric methods for estimating methionine and tryptophan to analyze defatted dhal samples. The 634 accessions analyzed for methionine ranged from 0.70 to 1.45, with a mean of 1.03 g/16 g N, and 460 accessions analyzed for tryptophan ranged from 0.53 to 1.11 with a mean of 0.75 g/16g N.

In conjunction with our breeders we determined protein contents of 338 single-plant selections in the F_7 generation. They came from crosses between Pant A-2 pigeonpea and two

Table 16. Comparison of high protein pigeonpea lines vs standard adapted cultivar at ICRISAT Center, rainy season 1981.

Pedigree and parentage[1]	Protein(%)[2]	
	Line	Check (C-11)
75S60F_5-26-3⊗	32.1	21.3
-48-9⊗	32.1	21.3
76175F_4-8⊗-4⊗ (a1)	31.3	21.4
75560F_5-44⊗-2⊗	31.1	21.7
-18⊗-3⊗	31.0	22.6
-44⊗-7⊗	30.7	21.7
-12-9⊗	30.7	21.4
-19-3⊗	30.6	22.6
-3⊗ ⊗	30.6	21.3
76175-8⊗-2⊗ (a1)	30.5	21.4

1. Plant A-2 x *A. scarabaeoides,* with *A. albicans* for pedigrees marked (al).
2. Estimated on dhal (dried, split seeds) basis.

high-protein *Atylosia* spp—*A. scarabaeoides* and *A. albicans.* Nearly 300 of the 338 selections had at least 25% protein and 18 had more than 30% protein; 10 with the highest protein are reported in Table 16. After evaluating their agronomic performances, we shall use the best ones as parents in future crosses.

This year our breeders made 30 crosses involving three high-protein and three low-protein parents to study the inheritance of protein levels. Reciprocal crosses were made to identify possible maternal effects.

To determine the effects of environment on protein content, we determined levels in early- and medium-maturing pigeonpea lines planted in different locations in India. Homogeneity of error variances indicated that the data sets from different locations of the EACT, ACT-1, and ACT-2 trials could be pooled. Location effects were significant for the short-season EACT and ACT-1 trials, but not for the medium-maturing ACT-2 trial. Genotype differences and interactions between genotypes and locations were highly significant in all three trials. The mean protein percentages for different locations are reported in Table 17.

Antinutritional Factors

To assay trypsin and chymotrypsin inhibitor activities in cooked dhal samples of 18 pigeonpea cultivars, we cooked the samples in a pressure cooker 15 minutes, then freeze-dried the samples with their broth. Cooking destroyed more trypsin inhibitor activity than chymotrypsin inhibitor activity (Table 18), but values varied widely among the cultivars. In no instance were the inhibitors completely destroyed by cooking, but cooking greatly reduced the extractability of the inhibitors.

The cooking process tended to increase in vitro protein digestibility of all the samples.

Values from cooked samples are compared with values from uncooked samples in Table 18.

Vegetable Pigeonpeas

We compared the nutritional compositions of immature vegetable pigeonpea seeds and gardenpeas. Total soluble sugars in general, and sucrose in particular, were considerably higher in gardenpeas than in pigeonpeas, while the

Table 17. Mean protein percentage of pigeonpea entries in EACT, ACT-1, and ACT-2 grown at indicated locations in India during 1980-81 rainy season.

EACT				ACT-1			ACT-2			
	Locations				Locations			Locations		
Cultivar	Berhampore	Nayagarh	S.K.Nagar	Cultivar	Junagarh	S.K.Nagar	Cultivar	Gulbarga	S.K.Nagar	Kanpur
ICPL-1	19.8	16.5	19.5	BDN-3	20.5	20.4	BDN 2	18.9	20.2	19.7
ICPL-81	19.8	16.5	21.1	Hy 1	21.9	18.9	ICPL-227	18.8	18.4	18.3
ICPL-86	18.6	16.8	22.0	S-5	21.5	19.9	20 (105)	19.4	18.6	17.9
ICPL-87	20.0	16.8	19.6	T.21	21.3	20.2	ICPL-42	19.1	19.4	19.6
DL 78-2	20.4	18.5	21.0	4-84	20.5	20.5	ICPH-2	19.7	21.0	20.4
ICPL-85	22.5	19.9	22.5	Hy 5	20.8	19.1	1CPH-5	17.9	17.9	19.6
H77-208	19.9	18.4	21.0	ICPL-8	21.0	19.9	ICPL-192	18.9	19.9	20.1
Pant A-10	20.6	16.9	20.2	S-80	20.9	18.1				
DL 78-1	20.9	17.8	20.8	DL 74-1	21.1	20.2				
				ICPL-95	20.8	19.6				
				ICPL-6	20.1	18.2				
SE±	0.42	0.22	0.40		0.20	0.34		0.24	0.58	0.30
CV(%)	3.6	2.2	3.3		1.9	3.5		2.5	6.0	3.0

Table 18. Effect of 15-min pressure cooking on trypsin and chymootrypsin inhibitors and in vitro protein digestibility of dhal samples prepared from 18 pigeonpea cultivars.

	Uncooked			Cooked		
Constituent	Range	Mean	SE	Range	Mean	SE
Protease inhibitors[1]						
Trypsin inhibitor activity (TIA)[1]	5.4-12.2	9.9	±0.4	0.5-2.0	1.1	±0.1
Chymotrypsin inhibitor activity (CIA)[1]	1.7-3.0	2.6	±0.1	0.1-0.3	0.2	±0.02
In vitro protein digestibility (IVPD)[2]	52.5-56.5	55.1	±0.4	59.4-83.4	77.1	±0.6

1. Units inhibited per mg meal.
2. Digestible nitrogen %.

flatulence-causing sugars (raffinose and stachyose) were higher in vegetable pigeonpeas.

The organoleptic qualities of freshly harvested Uncooked and cooked vegetable pigeonpeas from green and purple pods were evaluated by an eight-member taste panel. The overall acceptability of uncooked pigeonpeas from green pods was better than from purple pods. But cooking erased the differences, which indicates that cooking improves the acceptability of purple vegetable pigeonpeas.

Milling Quality

Using a barley pearler fitted with a wooden instead of a carborundum wheel, we investigated

Table 19. The milling quality of ten pigeonpea cultivars.[1]

			Yield of indicated fractions (%)		
Cultivar	100-seed wt (g)	Dehusked (%)	Dhal	Broken grains	Husk
C.11	9.4	96.7	75.4	9.0	12.3
Bahar	12.9	91.5	79.1	8.9	10.9
ICPL-227	10.0	90.2	53.8	25.6	10.9
T.7	11.8	89.7	71.1	10.0	8.6
Gwalior-3	8.5	89.4	63.6	13.4	12.5
Hy 4	8.6	77.2	55.6	11.2	10.0
NP(WR)-15	7.2	71.3	52.9	7.3	11.2
ICPL-6	6.8	69.4	48.9	11.3	9.1
BDN 2	7.4	65.9	54.2	3.4	8.6
LRG-30	6.5	60.0	43.2	8.9	10.8
Mean	8.9	80.1	59.8	10.9	10.5
Se ±	0.68	4.07	3.77	1.84	0.44
CV (%)	24	16	20	53	13

1. Average of 3 determinations.

the milling quality of 10 pigeonpea cultivars. Dehusking percentages ranged from 60.0 for the cultivar LRG-30 to 96.7 for the cultivar C 11 (Table 19). Dhal yield was 43.2% for LRG-30 and 75.4% for C 11. Two other milling fractions, broken grains and husk, ranged from 3.4% to 25.6% and 8.6% to 12.5%, respectively, for the 10 cultivars tested. Dehusking percentages of 60 germplasm accessions evaluated for milling quality ranged from 43.3 to 97.2.

Chemical Analyses of Podfly-tolerant Cultivars

In collaboration with entomologists we estimated total nitrogen, soluble nitrogen, soluble sugars, and total polyphenols compounds in leaf and stem tissues of 12 cultivars from low- or high-podfly incidence groups. Two replicates of each cultivar were grown in a randomized-block design on a Vertisol at ICRISAT Center. Plant samples obtained from the vegetative and flowering stages were analyzed. The same constituents were determined in seed and pod wall tissues of tender pods. Statistical analysis of the data indicated that no chemical constituent analyzed differed significantly between the two groups.

Plant Improvement

Extra-early and Early-maturity Pigeonpea

The area sown to early-maturity pigeonpeas increased substantially in northwestern India again this year. The main requirement of that area continues to be a pigeonpea that matures early enough to be harvested in time to allow timely seeding of winter wheat. Wheat cultivars can be sown well into December but farmers will not tolerate the marked yield reduction from sowing wheat late. Therefore work at our Hissar station is aimed at producing still earlier-maturing cultivars to be sown in June or July and yield as well or better than the early-maturing cultivars now used.

Because of the added benefits of yield from intercropping, reduced weed competition, and increased wood yield, more farmers are sowing in April early pigeonpeas and such early-maturing pulse crops as summer mung (*Vigna radiata).* We are continuing our research to identify pigeonpea cultivars suited to that cropping procedure by testing much of our breeding material at our Hissar station at more than one planting date.

In much of northwestern India pigeonpeas are generally not affected by such diseases as wilt, sterility mosaic, and phytophthora blight, which are prevalent in most of India. But cultivation of early-maturing pigeonpeas is being increasingly extended into areas of India where those diseases are prevalent. Additionally, whenever pigeonpeas are grown they may be attacked by insects, particularly *Heliothis* pod borer and podfly; so we are attempting to identify at ICRISAT Center, Patancheru, early-maturing lines that resist sterility mosaic, phytophthora blight, and wilt and are less susceptible to pod borers and podflies.

About half of the 120 crosses made at Hissar in 1982 were intended to incorporate disease resistance in early-maturing backgrounds. In addition, we screened 454 advanced lines at ICRISAT Center, Patancheru for resistance to sterility mosaic, wilt, and phytophthora blight.

Besides the lines reported in the 1981 ICRISAT Annual Report, we identified others in 1981 with promising yields and seed size that matured in less than 100 days (Table 20). They can provide farmers more time to prepare their fields for wheat, or they can be used where delayed seeding of pigeonpea is necessary. Their comparatively short stature (about 150 cm) makes them easy to manage and spray.

Medium-maturity Pigeonpea

The medium-maturing pigeonpea types are adapted to SAT areas with enough rainfall for a crop to grow 150 to 170 days without heavy drought stress. Such pigeonpeas are usually grown as an intercrop. For optimum yields, they must withstand attacks by wilt, sterility mosaic,

Table 20. Performance of some promising pigeonpea lines maturing in less than 100 days at the ICRISAT station, Hissar, India, rainy season 1981.

Lines	Days to flower	Days to mature	100-seed weight (g)	Yield (kg/ha)
ICPL-316	56	97	8.8	2510
ICPL-313	55	99	7.6	2450
Comp. 1 ODT-H7-HB	54	90	7.7	2430
Prabhat (Control)	74	118	6.1	2320
SE ±	0.7	6.3	0.21	108
CV (%)	1.9	9.8	4.5	8.8

and pod borers. Phytophthora blight and podfly may also reduce yields considerably.

In our 1981/82 crossing program at ICRISAT Center, we made 581 crosses designed to produce medium-maturity, high-yielding pigeonpea lines with insect and disease resistance and acceptable grain quality. Several medium-maturity, advanced lines derived from single, triple, and double crosses performed well during the 1981 rainy season, outyielding the standard control cultivars (Table 21). We are testing most of those lines during the 1982 rainy season at several locations, in India and elsewhere, as part of the Medium Maturity Pigeonpea Adaptation Yield Trial (MPAY).

Late-maturity Pigeonpea

We continued breeding late-maturity pigeonpea during 1981 at our Gwalior station where extremely high variability stemmed from poor growth in certain areas of the field. Despite the variability, we identified certain lines with promise. They are being tested at several locations in the Late Maturity Pigeonpea Adaptation Yield Trial (LPAY). ICPL-311, which performed well in the ACT-3 of the All India Coordinated Pulse Improvement Project, is being tested again in the ACT-3, along with ICPL-310.

In 1981 we also identified several promising short-statured, late-maturity lines whose performance we are evaluating this year.

Line Development

We continued to purify and maintain varieties and elite lines. We evaluated 34 inbred lines of ICP-6982-6, along with its open-pollinated bulk and C 11, in a replicated yield test. ICP-6982-6 is a line that has performed well when intercropped with sorghum. Of the inbred lines five significantly outyielded the open-pollinated bulk. One line, ICPL-304 from the cross (T. 21 x ICP-102) x (ICP-4726 x ICP-6986), was promising on the basis of good performance the past 3 years. It was entered in the 1982 ACT-2.

Hybrids

New hybrids. This year we are producing enough seed at ICRISAT Center of ICPH-8, (the early-maturity hybrid MS-Prabhat x ICPL-161) that yielded 3900 kg/ha in our trials at Hissarin 1981 (ICRISAT Annual Report 1981), to enter it in the EACT of the AICPIP during the 1983 rainy season. We are also producing a large quantity of seed of the hybrid ICPH-2 so it can be tested in the national mini-kit trials (prerelease on-farm trials) in 1983.

Using the diversity of genotypic backgrounds into which we have put the male-sterile character (ICRISAT Annual Report 1981), we produced several new hybrids; for example, 57 early-maturity hybrids using MS-Prabhat and MS-T. 21. Next year we will have enough seed to test 15

Table 21. Performance of indicated, medium-maturity advanced pigeonpea lines grown in several trials at ICRISAT Center, rainy season 1981.

Trial	Pedigree	Days to 50% flowering	100-seed weight (g)	Yield (kg/ha)
1	ICPL-296	95	8.6	1650
	Hy 4 (Control)	97	11.6	1560
	SE ±	0.9	0.17	132
	CV (%)	2	3.7	16
2	ICPL-272	131	9.7	2220
	C 11 (Control)	133	9.5	1760
	SE ±	1.0	0.21	72
	CV (%)	2	4.4	10
3	ICPL-318	128	10.6	2280
	ICPL-319	123	11.6	2180
	BDN 1 (Control)	127	10.7	1940
	SE ±	141.0	0.24	120
	CV (%)	141.4	4.1	12
4	ICPL-321	138	7.9	2420
	ICPL-322	136	7.1	2350
	ICPL-320	133	8.4	2340
	C 11 (Control)	133	10.3	2190
	SE ±	0.7	0.18	114
	CV (%)	0.9	3.5	10
5	ICPL-324 [a]	140	7.4	1880
	ICPL-323 [a]	139	7.1	1750
	C 11 (Control)	134	9.8	1690
	SE ±	0.6	0.14	132
	CV (%)	0.7	3.6	17
6	73094-13-G1-VIINDT1-4-VINDT4-B	134	9.3	2150
	C 11 (Control)	136	10.6	2080
	SE ±	2.0	0.30	157
	CV (%)	3.0	4.9	16
7	73076 F_4B-306-GB-GB-B⊗	128	9.4	2130
	C 11 (Control)	131	10.4	1940
	SE ±	1.3	0.33	140
	CV (%)	2.0	5.5	15

a. Inbred lines of ICP-6982-6.

A field worker in Hissar, northern India, emasculates a pigeonpea flower as part of making a hybrid. We continued to develop hybrids and progenies from hybrids to use more fully the diverse genotypic backgrounds we have assembled.

of the 57 new hybrids in a replicated yield test at our Hissar station. The remaining 42 are being grown in an unreplicated yield nursery at Hissar. Using other material from our newly converted male-sterile lines, we produced 19 medium-maturity hybrids of two types: medium- x medium-maturity and early- x late-maturity parents. We are testing all of them during this rainy season at ICRISAT Center.

Male-sterile conversion. In our male-sterile conversion program we completed four backcrosses onto eight diverse elite lines, ICP-102, -3783, -7086, -7105, -7118, -7120, BDN 1, and NP(WR)-15, in addition to the five reported last year (ICRISAT Annual Report 1981). The fourth backcross F,s of the eight new lines were sown this year, so we can make the final backcrosses using the appropriate recipient parent as the female, to avoid the possible danger of a single cytoplasm in all the lines.

Population Development

We initiated five male-sterile populations this year. After three generations of intermating we will select within them using mass, half-sib, and S_1 family population-improvement techniques. We will derive improved inbred lines from these populations and release them to cooperators for further selection. The selection goals include stable high yield in both late-and medium-maturity classes, with and without insect control. Each population carries resistance to the major pigeonpea diseases; otherwise the parentage of each population is determined by its selection goal.

Natural Outcrossing

To estimate the unintended outcrossing percentage on uncovered flowers after hand pollinations, we made crosses between green x green stem markers and obtuse x obtuse leaf markers. As these are both recessive markers, any outcrosses with adjacent normal plants give normal seedlings. The percentage of outcrosses was 10.7 from green x green and 5.4 from obtuse x obtuse. The results show a higher percentage of foreign pollen than those reported last year, and suggest caution when making crosses without protecting the emasculated flowers.

Rapid Generation Turnover

Our ability to advance material only one generation a year has limited our progress in breeding late-maturing pigeonpeas. Recent research in Australia and New Zealand indicated that pigeonpea flowering is inhibited by excessively high or low temperature, as well as by long days. With that information, we continued attempts to obtain two crops a year. That involved sowing 20 diverse genotypes in March in south India with its relatively short days from March to September. These sowings were in the Nilgiri and Palni Hills (that lie between about 10° and 11° 30'N) at six sites with a range of altitudes—to obtain an array of temperature regimes.

Data in Table 22 show the average growth stage of six lines in the late-maturity group. By mid-September we could harvest mature or near-mature seed from all six late-maturity lines at the Vegetable Seed Production Center in the Nilgiri Hills. We had previously reported obtaining seed from late-maturity lines between October and March at ICRISAT center (ICRISAT Annual Report 1975/76). Using the south India location, we can now obtain two generations a year of our late-maturing breeding material.

Cooperative Activities

International Trials

During 1982 we constituted a Pigeonpea Observation Nursery (PON) of 23 genotypes with a

Table 22. Effect of altitude on the average growth stage of six late-maturing pigeonpea lines seeded between 16 and 19 Mar 1982 in two hill ranges in South India and evaluated between 13 and 17 Sept 1982.

Location	Hill range	Latitude N	Altitude (m)	Average growth stage
Kallar	Nilgiri	11°21'	500	No floral buds
Masinagudi	Nilgiri	11°34'	1000	2 weeks before flowering
Pannaikadu	Palni	10°17'	1350	Early podding
Vegetable Seed Production Center	Nilgiri	11°21'	1450	Late podding
Kukkal Valley	Nilgiri	11°27'	1550	Late flowering
Shembaganur	Palni	10°14'	1850	1 week before flowering

This off-season crop of a late-maturing pigeonpea from Kenya was grown at 1450 m in the Palni hills of southern India—using the shorter days and lower temperatures there—to let us advance late maturity breeding lines two generations a year.

wide range of maturities, plant types, and disease and insect resistance to indicate the type of material that might be adapted where little or no pigeonpea had previously been grown. We sent the nursery to 20 locations in 14 countries. Additionally, we sent 15 adaptation yield trials containing our elite lines of early- (EPAY), medium- (MPAY), and late-maturity (LPAY) to seven countries other than India.

All India Coordinated Trials

Excellent cooperation with the All India Coordinated Pulses Improvement Project (AICPIP) continued this year. Several ICRISAT lines and hybrids were tested in the extra-early (EACT), early- (ACT-1), and medium-maturity (ACT-2) Arhar (pigeonpea) Coordinated Trials.

Our hybrids 1CPH-2, -5, and -6 continued to perform well when considered across all locations in the ACT-2 (Table 23). Combining all possible comparisons among the entries in the trials where these three hybrids were grown ranked them second, third, and fourth. Comparing the yield of our line 1CPL-270, a wilt-resistant selection from AS 71-37, with the original cultivar under disease-free conditions illustrates the difficulty of retaining yield in disease-resistant selections. Now, however, we have disease-resistant lines that yield as well as adapted controls under disease-free conditions.

Adaptation Yield Trials

We again made available to breeders, tests containing our most advanced breeders' lines. In 1981 our early-maturity trial of 20 entries, the medium-maturity trial of 25 entries, and the late trial of 16 entries, were sent to 10 appropriate locations. The yield, maturity, or seed size of some of them was extremely promising (Table 24). Performance in these tests is a criterion for putting them in the All India Coordinated Trials. For example, ICPL-I42 and ICPL-161 are in this year's EACT. These trials also permit breeders to select lines particularly suited to their locations.

Regional Trials

Each pigeonpea genotype tends to have a specific area of adaptation, so it is important to know the adaptability of each newly developed genotype to each region. Three regional trials were formulated for Andhra Pradesh, India, for the 1981/82 rainy season in cooperation with APAU and the 1ARI Regional Station, Hyderabad. Those three trials contained the most advanced, locally adapted material available from each of the cooperators. The first trial, ART-1, consisted of normal-spreading types; the second, ART-2, of erect types; and the third,

Table 23. Performance of ICRISAT pigeonpea entries in the 1981 rainy season ACT-2.

Entries	100-seed weight (g)	Height (cm)	Days to maturity	Yield (kg/ha)								
				NPE zone	Central zone		Peninsular zone					Average of 7 common locations
	ICRISAT Center	ICRISAT Center	Mean 6 locations	Sabour 17[a]	Jabalpur 16	Sehore 17	Jalna 18	Lam 15	Badnapur 19	Coimbatore 17	ICRISAT Center 19	
ICPH-2	8.4	163	169	1220 (5)[b]	1620 (5)	1920 (5)	3730 (2)	1750 (1)	840 (8)	570 (7)	1120 (10)	1650
ICPH-5	8.6	197	179	1130 (6)	1900 (1)	2000 (3)	3110 (7)	1670 (2)	790 (14)	820 (4)	1220 (7)	1650
ICPH-6	8.6	179	175	880(10)	1790 (2)	1870 (6)	3080 (8)	1490 (4)	890 (7)	750 (5)	1240 (5)	1590
ICPL-270	11.9	175	169	1460 (4)	1100 (12)	2110 (2)	2190 (12)	1340 (9)	970 (5)	400 (11)	1060 (13)	1310
C 11 (Control)	10.0	170	182	NR[c]	1690 (3)	1930 (4)	2950 (9)	1340 (9)	830 (10)	570 (6)	1090 (11)	1480
AS 71-37 (Control)	11.2	158	167	1650 (3)	1640 (4)	2140 (1)	3680 (4)	NR	970 (5)	440 (10)	1300 (3)	1690
SE ±	0.22	7	-	136	105	205	31	98	43	25	128	
CV (%)	4.0	8	-	24	16	25	16	15	10	10	23	

a. Number of entries in each trial.
b. Yield rank within trial.
c. NR = not reported.

ART-3, was intercropped with sorghum. Each contained an upright (Hy 4) and a spreading (C 11) control. The tests were conducted at six locations, four on Vertisols, and two on Alfisols. Yields of the ICRISAT entries compared with the highest yielding check were encouraging for ICPL-265, -296, and -272, which are being tested again this year to confirm their superiority. Similar regional trials for early-maturity pigeonpeas have been organized this year in four other states in India.

ICAR-ICRISAT Disease Nurseries

The second Indian Council of Agricultural Research (ICAR) and ICRISAT Uniform Trial for Pigeonpea Wilt Resistance (IIUTPWR) consisting of 20 entries, 16 of which were contributed by ICRISAT, was conducted at 11 locations in India. Two entries contributed by ICRISAT, ICP-8863 and cross 74342, had less than 20% wilt at all six Alfisol locations (Annigeri, Badnapur, Berhampore, Dholi, Gulbarga, ICRISAT Center) and at all five Vertisol locations (Jabalpur, Kanpur, New Delhi, Ranchi, ICRISAT Center). Five other entries, ICP-7118, -7182, -10957, -10960, and -11299, did well across 10 locations. Several other entries did well at more than one location. Based on its good performance across all locations in India, ICP-8863 was recommended by AICPIP for use in breeding programs developing wilt-resistant cultivars.

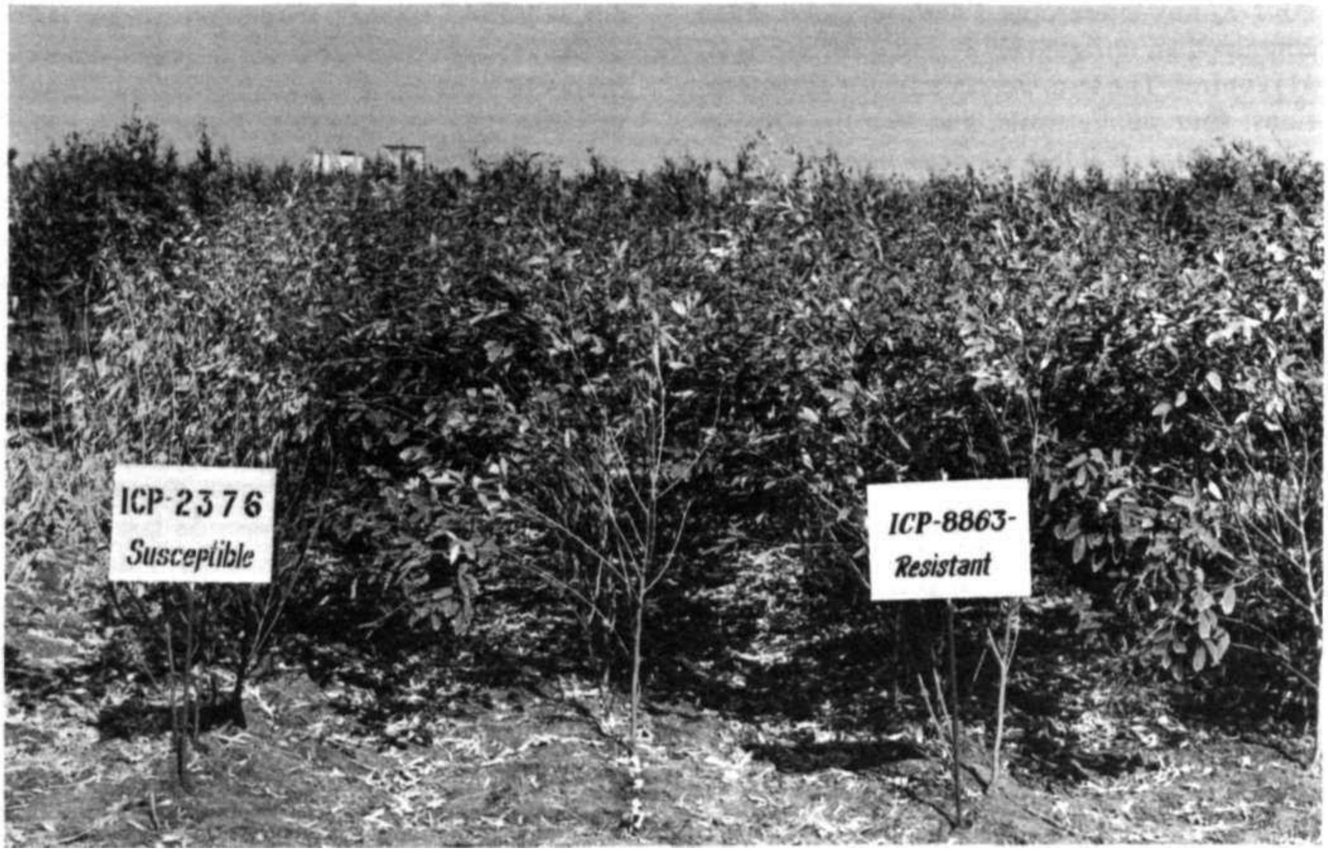
Similarly the second cooperative ICAR and ICRISAT Uniform Trial for Pigeonpea Sterility Mosaic Resistance (IIUTPSMR) consisting of 21 entries, of which 20 were contributed by ICRISAT, was grown at seven locations: Badnapur, Dholi, ICRISAT Center, Kanpur, Ludhiana, Vamban, and Varanasi. As last year, all lines reacted similarly at Badnapur (Maharashtra) and ICRISAT Center. Most of the lines were susceptible at Dholi (Bihar), Kanpur(Uttar Pradesh), Ludhiana (Punjab), and Vamban (Tamil Nadu). Entry ICP-5124, however, was resistant at Dholi; entries ICP-4395 and ICP-7234, at Kanpur; and entry ICP-7378 at Vamban. Some entries showed resistant or tolerance at all three locations, which indicates that there are different strains of the causal agent, or ofthe

Table 24. Performance of five top yielding pigeonpea lines and the checks in the Early Maturity Adaptation Yield Trial at five locations in the North Plains West Zone, rainy season 1981.

	At Hissar (ICRISAT)			Yield (kg/ha)					
Entries	Days to flower	Days to mature	100-seed weight (g)	HAU Hissar	ICRISAT Hissar	Delhi	Pantnagar	Sriganga-nagar	Mean
ICPL-142	86	145	7.2	2170(4)[a]	3570(1)	3360(2)	2570(1)	3000(2)	2930
ICPL-155	77	137	8.3	2330(2)	2300(6)	3220(4)	2300(7)	2760 (3)	2580
ICPL-161	90	145	8.9	2280(3)	2260(8)	2870(7)	2320 (5)	2580 (5)	2460
ICPL-154	.75	131	8.9	2110(6)	2520(3)	2360(11)	2370 (2)	2190 (6)	2310
ICPL-148	78	122	8.8	1670(13)	2240(10)	3270(3)	2150(8)	2200(10)	2300
UPAS 120 (Check)	86	149	7.2	2610(1)	1560(20)	na[b]	2360 (3)	2610 (4)	2290
Prabhat (Check)	70	118	6.5	1720 (14)	2100 (12)	1920 (16)	2110(9)	2330 (5)	2040
SE±	0.5	2.6	0.3	164	160	108	495	191	-
CV (%)	1.2	3.2	6.0	14.3	13.2	7.3	34.1	17.1	-

a. Yield rank within trial

b. na = not available.



Based on good performance over the past few years across 11 locations in India, ICRISAT pigeonpea ICP 8863 (growing at right while the susceptible line stands wilted at left) has been recommended by AICPIP for use in breeding programs to develop wilt-resistant cultivars.

vector at different locations. We are planning a study next year to find reasons for the differences.

Testing for Wilt Resistance in Kenya and Malawi

Considering the importance of pigeonpea wilt in Kenya and Malawi, we sent some lines with promising wilt resistance at ICRISAT Center to be tested in those two countries during the 1980/81 season. Of 38 lines tested in a wilt-sick plot at Katumani, Kenya, lines ICP-9145,-9155, and -10960, were resistant, and ICP-8864,-10957, and -11295 showed some resistance. Those six lines, along with other promising lines from ICRISAT, are being tested again at Katumani during the 1981/82 season.

In Malawi, 12 lines from ICRISAT were tested in a wilt-sick plot at Byumbwe during the 1980/81 season. Lines ICP-9139, -9142, -9145, and -9148 were free from wilt, and ICP-9134, -9147, -9156, and -9177 were resistant. Further testing of those eight lines, and other promising lines from ICRISAT, is in progress.

University of Queensland

Our work at the University of Queensland continued in 1982. ICRISAT's funding of this program formally terminated in November 1982. But the University will continue the program under alternative funding.

Our 5-year association with the University of Queensland has been extremely fruitful. One of our scientists worked at the University $2^1/_2$ years, funded by a Commonwealth of Australia Special Research Grant. Exchange visits between Queensland and ICRISAT Center strengthened the program, and we collaborated in developing pigeonpea programs at each other's institutions. Primarily, this program has developed a production system with early-maturing pigeonpea cultivars that produce outstanding yields (Tables 25 and 26). An improved production system has been researched and accepted in Fiji, and its adoption is expected to make that country self-sufficient in pigeonpea production. Work by the University of Queensland staff has provided a better understanding of the control and inheritance of flowering as influenced by photoperiod and temperature. The program also has identified two new sources of genetic male sterility and a mechanism that may ensure selfing, and has developed photoperiod-insensitive lines and fast-ratooning lines. Genetic material from this program has been sent to many parts of the world. A cultivar, Hunt, was released in Queensland in 1982.

The 1982 season in southeastern Queensland was generally favorable with rainfall well distributed in many areas. Crop growth was mostly

Table 25. Yields of the highest yielding early-maturing pigeonpea lines and the control cv Prabhat in replicated tests at four locations in Australia, 1982.

Location	Population (plants/ha)	Entry	Pedigree	Days to 50% flowering	100-seed weight (g)	Yield (kg/ha)
Redland Bay	500000	QPL-67	ICP-6997 x Prabhat	67	9.5	6310
		QPL-17	HAU line	60	8.6	4780
		Prabhat		60	7.2	4650
		QPL-58	Prabhat x ICP-6997	60	9.5	4200
		QPL-61	Prabhat x ICP-6997	69	11.7	4200
		Trial Mean (n = 16)				3790
		SE				±436
		CV (%)				19.8
Kingaroy	500000	QPL-61	Prabhat x Baigani	68		6320
		QPL-40	(Prabhat x ICP-8405)x ICPL-10	63		5050
		QPL-58	Prabhat x ICP-6997	66		5030
		QPL-67	ICP-6997 x Prabhat	69		4960
		Prabhat		62		3170
		Trial Mean (n - 23)				3930
		SE				± 283
		CV (%)				12.5
Gatton	500000	QPL-67	ICP-6997 x Prabhat		9.7	5560
		QPL-58	Prabhat x ICP-6997		10.5	4930
		QPL-17	HAU line		7.6	4730
		Prabhat			5.4	2860
		Trial Mean (n = 16)				3730
		SE				± 561
		CV (%)				26.1

Table 26. Performance of some breeding lines fan replicated yield trials at Redland Bay, Queensland, Australia, 1982.

Entry	Pedigree	Days to 50% flo-wering	100-seed weight (g)	Yield (kg/ha)
QPL-130	ICP-6997 x Prabhat	60	12.3	6510
QPL-126	ICRISAT Cross 74075	64	10.3	5560
QPL-134	Prabhat x Hy 3C	60	10.0	5290
Prabhat	(Check)	60	7.2	5240
Trial Mean (n = 50)				3800
SE				±412
CV (%)				18.8
QPL-131	ICP-6997 x Prabhat	64	11.7	8070
QPL-132	ICP-6997 x Prabhat	61	11.6	7540
Prabhat	(Check)	60	7.0	5470
Trial Mean (n = 15)				4170
SE				±430
CV (%)				17.6
QPL-503	(Prabhat x ICP-8504) x CPL-10	66	11.9	8880
QPL-511	(Prabhat x ICP-8504) x ICPL-10	70	13.8	6690
QPL-536	(Prabhat x ICP-8504) x ICPL-10	65	11.2	6420
Prabhat	(Check)	60	7.2	4790
Trial Mean (n = 362)				3210
SE				±517
CV (%)				22.8
QPL-246	*C. cajanus* x *A. lineata*	87		4990
QPL-247	*C. cajanus* x *A. lineata*	89		4090
QPL-242	Prabhat x C-322	85		3250
C-322	(Check)	91		2400
Trial Mean (n = 50)				2240
SE				±241
CV (%)				18.6

excellent, except that extremely wet and overcast conditions at Redland Bay during flowering and early pod set of the earliest maturing lines drastically reduced pod set from the first flush of flowers. Subsequent flowering, pod set, and seed yield there were excellent.

Inheritance of photoperiod-sensitivity. These studies continued in 1982. The lines showing differential response are being stabilized. They will be selfed for reevaluation next year and lines in the various response classes that appear homozygous will be intercrossed to test our hypothesis regarding inheritance of this trait.

In addition we carried out a detailed study of time-to-flowering in a further series of F_2 populations grown at two sowing dates.

Photoperiod x temperature interactions. Attaining rapid generation turnover is critical in breeding. But the factors influencing floral induction and initiation and flower development in pigeonpea are poorly understood, partly because it is difficult to use controlled environment facilities for the later pigeonpea germplasm that grows to extremely large size and may take 200 days or more to flower. Thus we have had to use field trials to investigate the effects of environmental factors on flowering.

Detailed studies on the effects of photoperiod, temperature, and their interaction on floral initiation and development in early-flowering pigeonpeas have been completed, using field and controlled-environment facilities. Control of flowering in late genotypes remains unclear, although our trials at several latitudes and altitudes in India indicate that late genotypes can be made to flower rapidly. This year a program was initiated in Bali, Indonesia, to study flowering response—funded by the Australian Universities International Development Program and the Department of Agriculture, University of Queensland, The topography of Bali allows pigeonpeas to grow at sites with the same latitude (8^0S) but at different altitudes, which varies temperature regimes. Artificially extending the photoperiod has permitted us to make a factorial study of photoperiod and temperature.

Germplasm from ICRISAT, Kenya, and the University of Queensland, and several F_2 populations involving photoperiod-sensitive and insensitive parents are being evaluated at three altitudes for initiation and flowering. Preliminary results from the experiment, still in progress, confirm that initiation and flowering of late lines can be accelerated. The study should provide useful additional information on photoperiod x temperature interactions on floral development in pigeonpea, and perhaps help develop procedures for rapid generation turnover.

Regional yield evaluation. Yields from six regional tests in Queensland, Australia were encouraging (Table 25), and confirm the high seed-yield potential from short-season pigeonpeas grown in dense populations. Besides increasing yields, we have also improved seed size and seeds per pod in these lines.

The high plant populations we used in Australia suppress branching and result in synchronized flowering and pod maturity. This greatly assists insect control. Apart from Redland Bay, a vegetable-growing area with continuous insect problems, we found that no more than four sprays at any site gave excellent insect control. Such a spray schedule is typical for crop species in trials in these areas.

We observed remarkable homeostatic ability for seed yield, associated with the perennial habit. At Gatton, on a heavy black soil, insect control at flowering was neglected for various reasons, and the first flush of flowers was destroyed by *Maruca* spp. With subsequent insect control, the second flush set well and produced high yields despite a delayed harvest (Table 25). Similarly at Redland Bay, high seed yields were attained from the second flush of flowers after early flowering lines had extremely poor initial pod set due to overcast skies. The perennial habit is highly important in conditioning homeostatic performance in early-maturing pigeonpea, by allowing it to respond to variable climatic and insect challenges.

Preliminary evidence this year suggests that some of our breeding lines can produce even higher yields (Table 26). Some of the lines gave relatively high yields at all test sites. Next year we will evaluate a wider range of entries and sites.

Release of photoperiod-insensitive cultivar. In cooperation with the Queensland Graingrowers Association we have increased seed of QPL-96 for release to growers under the name 'Hunt'. QPL-96, from the cross Prabhat x Baigani in our breeding program in India, has been tested 3 years in Queensland. It is relatively insensitive to photoperiod, flowers in about 65 days, and has brown seeds approximately 10 g/100 seeds. Plant populations of around 400 000 per hectare are required for maximum yields.

Distribution of Breeders' Material

In addition to our entries in the All India Trials, we supplied 3302 pigeonpea samples to various breeders on request. Forty scientists in 28 countries other than India received 1227 samples; 53 scientists at 39 locations in India received 2075 samples. The materials despatched include F_1S, F_2s, segregating progenies, advanced lines, disease-resistant lines, male-sterile stocks, and newly converted male-sterile progenies.

Looking Ahead

We will continue to search for resistance to wilt, sterility mosaic, and phytophthora blight with special attention to broadening our genetic base for resistance to all three. We are particularly interested in identifying a source of resistance to P3 isolate of phytophthora blight. Our multilocation testing will help identify both the most widely resistant material and potential new races.

Two ICRISAT-developed pigeonpea varieties are being considered for release to farmers in India: ICPL-87 (above) in Gujarat, and ICPL-92 in Himachal Pradesh.

We expect to expand the pheromone-trap network monitoring *Heliothis armigera* populations, in India and in neighboring countries. When we understand the relationship ofthe trap populations with field populations, along with climatic and cropping effects, we should be able to predict damaging infestations and thus allow timely control.

We shall continue to study ureides and other nitrogenous transport compounds as a means of evaluating nitrogen, fixation, while continuing attempts to improve the acetylene-reduction assay. We will evaluate our collection of effective *Rhizobium* strains to identify the most competitive ones. Our selection for improved fixation will be concentrated initially on advanced breeders' lines, in which selfing has reduced the extreme plant-to-plant variability.

We shall continue efforts to identify high-yielding production systems for our new early-maturing lines.

We also will be looking for chemical factors within plants related to disease and insect resistance, and for factors related to high vegetable quality.

Creating and testing new hybrids with the many new male-sterile lines we have now developed should provide some high-performing combinations. We will continue emphasis on developing extremely early lines with high yields on shorter plants. We will work closely with the national programs in coordinating crosses for disease resistance, testing lines over a wide range of environments, and providing meetings at ICRISAT where breeders can share ideas and select material that may be useful to them.

Publications

Institute Publications

NENE, Y.L., KANNAIYAN, J., and REDDY, M.V. 1981. Pigeonpea disease: resistance-screening techniques, information Bulletin No. 9. Patancheru, A.P., India: ICRISAT.

Journal Articles

BYTH, D.E., SAXENA, K.B., and WALLIS, E.S. 1982. A mechanism of inhibiting out-crossing in pigeonpea. Euphytica 31(2): 405-408.

DUNDAS, I.S., SAXENA, K.B., and BYTH, D.E. 1981. Microsporogenesis and anther wall development in male sterile and fertile lines of pigeonpea (*Cajanus cajan* [L.] Millsp.). Euphytica 30{2):431-435.

DUNDAS, I.S., SAXENA K.B., and BYTH, D.E., 1982.. Pollen mother cell and anther wall development in a photoperiod-insensitive male sterile mutant in pigeonpea *(Cajanus cajan* [L] Millsp.). Euphytica 31(2):371-375.

JAMBUNATHAN, R., and SINGH, U. 1981. Relationship between total sulphur and sulphur amino acids in chickpea (*Cicer arietinum* L.) and pigeonpea *(Cajanus cajan* [L.] Millsp.). Qualitas Plantamm—Plant Foods for Human Nutrition 31:109-117.

KRISHNAN, T.G., and REDDY, L.J. 1982. Species affinities between *Cajanus cajan* and some *Atyhsia* species based on esterase isoenzymes. Euphytica 31:1-5.

NENE, Y.L., and KANNAIYAN, J. 1981. Screening pigeonpea for resistance to Fusarium wilt. Plant Disease 66:306-307.

SAXENA, K.B., and SHARMA, D. 1981. Variation for leaf characteristics and relationship with grain yield and seed size of pigeonpea. Indian Journal of Genetics and Plant Breeding 41(3):340-345.

SAXENA, K.B., WALLIS, E.S., and BYTH, D.E. 1980. Development of photo-insensitive male sterile line of pigeonpea (*Cajanus cajan* [L.] Millsp.). Tropical Grain Legume Bulletin 20:22-23.

SHARMA, D., and JODHA, N.S. 1982. Pulses production in semi-arid regions of India: constraints and opportunities. Economic and Political Weekly 17(52), 25 Dec 1982:A135-A148.

SHARMA, D., KANNAIYAN, J., and REDDY, L.J, 1982. Inheritance of resistance to blight in pigeonpeas. Plant Disease 66:22-25.

SINGH, U., and JAMBUNATHAN, R. 1981. Methods for the estimation of protein in pigeonpea

(*Cajanus cajan* [L.] Millsp.) and the relationship between whole grain and dhal protein contents. Journal of the Science of Food and Agriculture 32:705-710.

SINGH, U., and JAMBUNATHAN, R. 1981. Protease inhibitors and *in vitro* protein digestibility of pigeonpea *(Cajanus cajan* [L.] Millsp.) and its wild relatives. Journal of Food Science and Technology 18:246-247.

VENKATESWARLU, S., and REDDY, L.J. 1980. Effect of different chemicals on the pod setting of male sterile strains of pigeonpea. Tropical Grain Legume Bulletin 20:26-27.

Conference Papers

BHATNAGAR, V.S., LATEEF, S.S., SITHANANTHAM, S., PAWAR, C.S., and REED, W. 1982. Research on *Heliothis* at ICRISAT. Pages 385-396 *in* Proceedings, International Workshop on *Heliothis* Management, 15-20 Nov 1981, ICRISAT, Patancheru, A.P., India: ICRISAT.

JAMBUNATHAN, R., SINGH, U., and SUBRAMANIAN, V. 1981. Grain quality of sorghum, pearl millet, pigeonpea, and chickpea. Presented at the UNU-ICRISAT-NIN-CFTRI Workshop on Interfaces between Agriculture, Nutrition, and Food Science, 10-12 Nov 1981, ICRISAT, Patancheru, A.P., India.

KANNAIYAN, J., NENE, Y.L., and REDDY, L.J. 1981. Phytophthora blight of pigeonpea. Presented at the First International Symposium on Phytophthora: Its Biology, Ecology, and Pathology, 1-4 Apr 1981, University of California, Riverside, USA.

REED, W.,and PAWAR, C.S. 1982. *Heliothis spp:* a global problem. Pages 9-14 *in* Proceedings, International Workshop on *Heliothis* Management, 15-20 Nov 1981, ICRISAT, Patancheru, A.P., India: ICRISAT.

SITHANANTHAM, S., BHATNAGAR, V.S., JADHAV, D.R., and REED, W. 1982. Some aspects of *Trichogramma* spp. parasitism in eggs in *Heliothis armigera* (Hb.) (Lepidoptera: Noctuidae). Presented at the First International Symposium on *Trichogramma,* 2-23 Apr 1982, Antibes, France.

GROUNDNUT

Contents

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GROUNDNUT

Groundnut production in the semi-arid tropics (SAT) exceeds that of any other legume and comprises 70% of the world's production. Approximately 25% protein and 50% edible oil, groundnuts are an important source of food and cash to SAT farmers. Groundnut yields in the SAT arc generally low, around 800 kg/ha, and fluctuate widely from unreliable rainfall. The low yields stem mainly from disease and pest attacks and drought stress. Answers to those problems would lead to greatly increased yields.

In the Groundnut Improvement Program we are working on disease and pest problems, nitrogen fixation, drought stress, and on improving yield and quality. Our continuing management strategy is to use the genetic diversity in groundnut and its wild relatives to breed into the crop stable resistance or tolerance to the major yield reducers.

Diseases

Some of the many diseases that attack groundnuts in the SAT cause large pod and haulm losses. The most important and widespread fungus diseases are the leaf spots, incited by *Cercospora arachidicola* and *Cercosporidium personatum,* and rust, incited by *Puccinia arachidis.* Pod rots, caused by a complex of soil fungi, are important in some regions and their damage is probably much underestimated.

Contamination of groundnut seeds and products with aflatoxins and other mycotoxins is a worldwide problem. Virus diseases are also important. Peanut mottle virus disease, which is seedborne, is widely distributed and causes significant yield losses. Other virus diseases are more restricted but where they occur they can severely damage groundnuts. Although nematode diseases are infrequent, they can cause significant damage and may be linked to pod and root rots. Groundnuts' only important bacterial disease is the wilt caused by *Pseudomonas solanacearum.* The wilt has not been found in India so we have done no research on it at ICRISAT.

Foliar Fungal Diseases

Screening for resistance. 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 1981/82 postrainy and 1982 rainy seasons. All resistances were confirmed. The disease ratings closely agreed with previous ratings, indicating stable resistance.

The fight against leaf diseases: resistance to rust and late leaf spot diseases—shown here—was confirmed this year in all groundnut germplasm lines previously rated high for this trait, thus indicating stable resistance.

Table 1. Yields (kg/ha) of selected groundnut genotypes resistant and susceptible to foliar diseases, ICRISAT Center, postrainy season 1981/82 and rainy season 1982.

	Pods		Haulms	
Genotypes	1981/82	1982	1981/82	1982
PI 215696	4280	64	9630	2150
PI 259747	5330	279	8490	3880
PI 298115	2590	840	9100	2840
PI 314817	6170	1180	6920	2490
PI 341879	5150	266	8660	3450
PI 390593	5620	715	8170	3020
PI 350680	4440	244	8090	3050
PI 393516	5080	62	9200	2980
PI 393517	7260	1180	9400	3100
PI 393531	6360	700	6670	3270
PI 407454	6640	1210	9380	3460
PI 405132	5440	447	11460	3520
NC Ac 17142	7040	450	7960	3330
EC 76446 (292)	3810	389	8180	3725
Krap. Strain 16	5120	468	8640	3060
RMP 12	3820	750	9120	3190
J 11 [a]	4760	252	5120	1290
TMV 2 [a]	4310	124	5840	1010
Robut 33-1 [a]	5140	409	6560	1810
SE	±396 [b]	±136	±682	±331
	± 404 [c]	±138	±695	±337
CV (%)	9.8	24.8	10.2	14.2

a. Foliar diseases-susceptible released high-yielding cultivars.
b. For genotypes appearing in the same block.
c. For genotypes not appearing in the same block.

Yield evaluation of foliar disease resistant lines. Forty-five germplasm lines with resistance to rust and/or late leaf spot diseases and late leaf spot-susceptible cultivars J 11, TMV 2, Robut 33-1, and M 13 were tested for yield in the 1981/82 postrainy season and the 1982 rainy season in field trials in a 7x7 triple-lattice design. The postrainy-season trial was irrigated when necessary and fully protected from insect pests; the rainy-season trial received no irrigation and no pesticides. Pod and haulm yields for selected genotypes are shown in Table 1.

Disease pressure was low and yields high in the postrainy season, but disease pressure was high and yields low in the rainy season. Despite low disease pressure in the postrainy season, three resistant lines significantly outyielded Robut 33-1. Some germplasm lines outyielded released cultivars in the rainy season. The efficiency of the triple-lattice design over the randomized block ranged from 101 to 116%.

Effect of chlorothalonil on groundnut yields. In the 1981/82 postrainy season genotypes TMV 2 and Robut 33-1, both susceptible to rust and late leaf spot diseases, and PI 259747, which resists

Table 2. Effect of chlorothalonil on rust and late leaf spot development and on yield of three groundnut genotypes, ICRISAT Center, postrainy season 1981/82.

			Yield (kg/ha)					
	% RGL [a]		Pods		Haulms		Shelling (%)	
Genotypes	W [b]	C [c]	W [b]	C [c]	W [b]	C [c]	W [b]	C [c]
TMV 2[d]	52.2	100.0	3297	2867	4375	5601	71.2	70.5
Robut 33-1[d]	62.7	100.0	3503	4160	5141	6613	71.0	65.7
PI 259747 [c]	97.2	100.0	3879	3722	5925	6478	58.5	62.3
SE	±1.32		±338.1[f] ±284.2[g]		±400.5[f] ±432.8[g]		±1.63[f] ±3.71[g]	
CV(%)			11.6		8.6		3.0	

a. = Percentage remaining green leaf.
b. = Water spray.
c. = Chlorothalonil spray.
d. = Susceptible to rust and leaf spots.
e. = Resistant to rust and leaf spots.
f = Standard error of the differences between two subplot treatment means at the same level of the main plot treatment.
g. = Standard error of the differences between two main plot treatment means for the same subplot treatment mean or for different levels of the subplot treatment.

both diseases, were given two spray treatments eight times each: water (500 liter/ha) and the fungicide chlorothalonil (1.28 kg a.i. in 800 liter water/ha). Rust and late leaf spot diseases were present at low levels. The percentage of green leaf remaining at harvest, haulm yields, pod yields, and shelling percentages are shown in Table 2. Further trials are needed to better understand chlorothalonil's effects on the diseases and yields.

Influence of host genotype on uredospore production. We studied uredospore production by *Puccinia arachidis* on rooted, detached leaves

Table 3. Uredospore production by *Puccinia arachidis* on six groundnut genotypes.

Genotypes	Mean pustule area (mm^2) [a]	Spores/ pustule [b]	Spores/mm^2 pustules area
TMV 2 (SE)[c]	1.2 (±0.069)	1015 (±97.275)	855 (±47.879)
EC 76446 (292)	0.4	22	61
NC Ac 17090	0.4	50	121
PI 405132	0.7	84	127
PI 407454	0.3	47	139
PI 393643	0.4	48	121
SE	±0.05	±17.8	±38.0

a. Calculated from the pustule diameter measured 31 days after inoculation.
b. Mean uredospore production during 13 to 35 days after inoculation.
c. Rust-susceptible cultivar.

of the rust-susceptible genotype, TMV 2, and five rust-resistant genotypes: EC 76446 (292), NC Ac 17090, PI 405132, PI 407454, and PI 393643. Significantly fewer uredospores were produced per unit of leaf area and per unit of pustule area on the resistant genotypes than on susceptible TMV 2 (Table 3 and Fig. 1).

Uredospores from resistant genotypes had significantly lower germinability than those from moderately resistant genotypes (Table 4), but we found no differences in uredospore morphology (Fig. 2).

Reduced uredospore production and germination are significantly related to rust disease buildup, so genotypes with those characters have a particular advantage.

Biological control of rust and late leaf spot diseases. We found the fungus *Verticillium lacanii* parasitizing rust and late leaf spot fungi in an 1CRISAT glasshouse. Preliminary research confirmed the pathogenicity of this fungus on both foliar disease pathogens. Applying spores of *V. lacanii* to rooted detached leaves of groundnut cultivar TMV 2, either before or when inoculating with spores of the rust and late leaf spot pathogens, considerably reduced development of the rust disease (Table 5).

Table 4. Germinability of uredospores of *Puccinia arachidis* collected from pustules on 19 groundnut genotypes.

		Percentage germination of uredospores sampled at:				
Genotype	Field rust score [a]	First rupture of pustules	5 days later	10 days later	15 days later	Mean uredospore germination(%)[b]
NC Ac 17090	2.1	29.8	32.5	40.3	46.3	37.2
PI 414332	2.5	34.6	37.4	38.0	38.7	37.2
PI 341879	2.5	54.5	54.9	45.7	41.3	49.1
PI 393646	2.5	54.5	49.4	50.6	45.0	49.9
PI 405132	2.5	59.5	53.4	37.8	41.5	48.1
PI 414331	2.8	30.9	21.6	47.7	45.3	36.4
PI 407454	2.8	31.9	38.5	50.4	49.6	42.6
PI 390593	2.8	33.9	41.2	60.2	32.7	42.0
PI 315608	3.0	23.0	16.2	19.3	33.3	23.0
PI 393527-B	3.0	30.1	33.0	51.7	56.4	42.8
PI 314817	3.0	35.8	45.7	51.6	39.4	43.1
EC 76446 (292)	3.0	45.4	64.0	44.3	38.7	48.1
PI 393643	3.0	47.1	38.3	44.7	43.3	43.3
PI 381622	3.0	50.2	35.7	38.1	33.1	39.3
PI 259747	3.0	57.9	50.7	44.5	49.4	50.6
NC Ac 17127	4.1	59.3	71.9	82.4	76.9	72.6
Robut 33-1 [c]	9.0	69.2	73.9	82.5	67.3	73.2
TMV 2 [c]	9.0	59.3	77.9	85.1	78.0	75.1
J 11 [c]	9.0	65.7	83.8	82.7	68.7	75.2
SE		±3.54	±3.01	±3.15	±3.89	
CV (%)		14.4	11.8	11.7	15.2	

a. Mean of field rust scores on a 9-point scale; 1 = no disease and 9 = 50 to 100% foliage destroyed.

b. Analyzed after eliminating the sampling time differences.

c. Rust and late leaf spot susceptible cultivars.

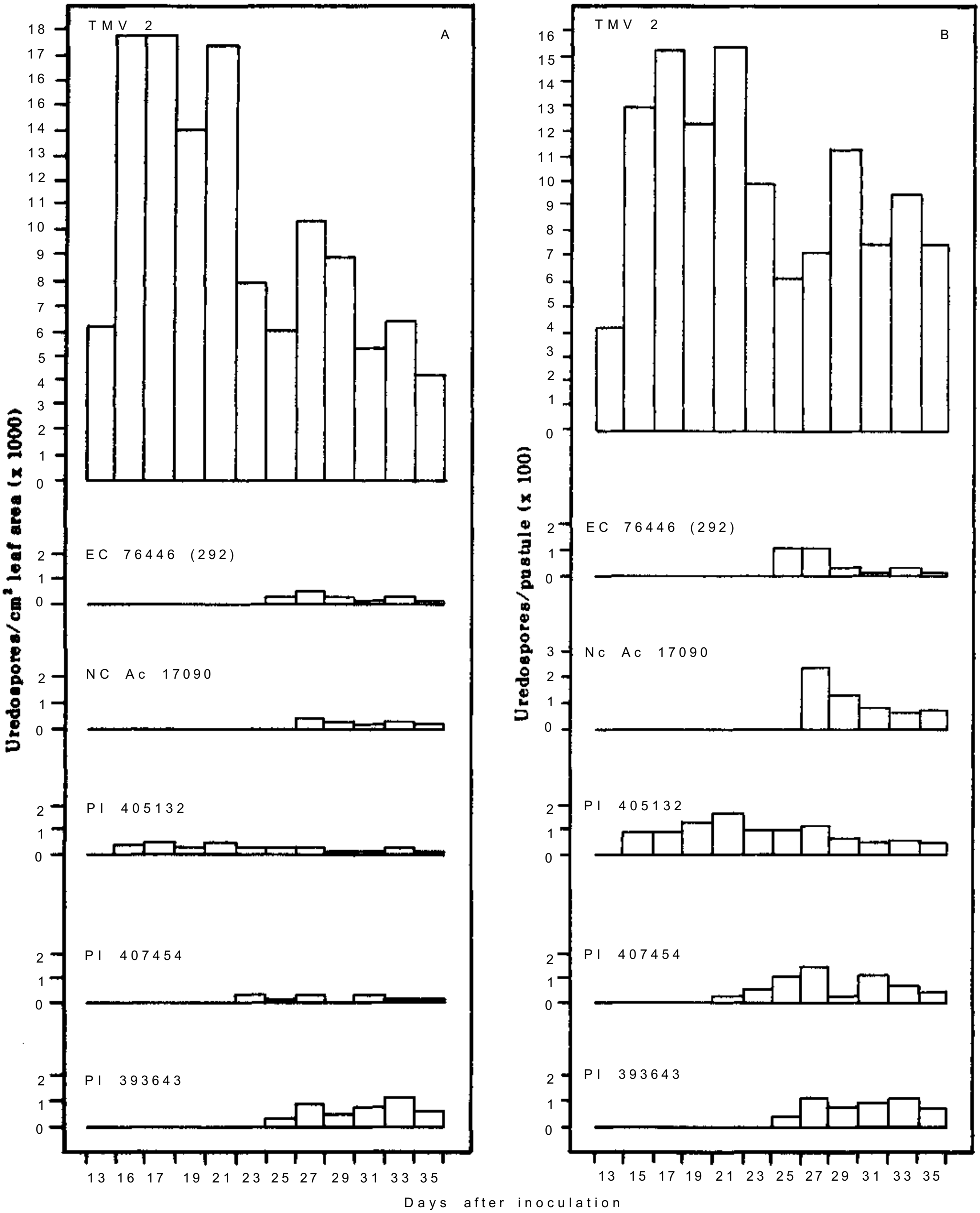
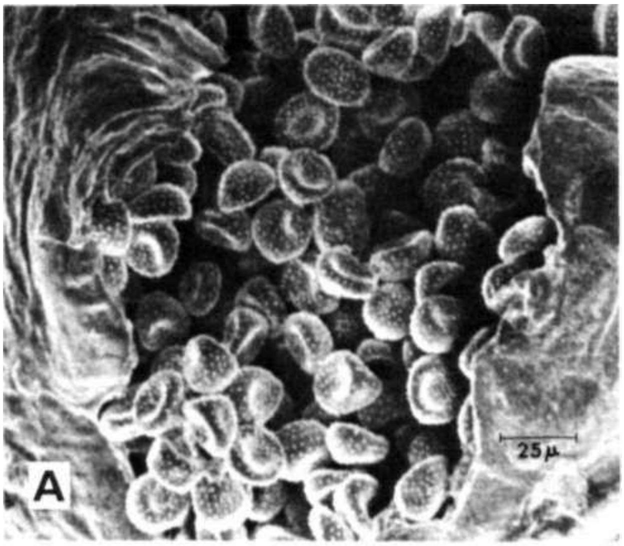


Figure 1. Production of uredospores of *Puccinia arachidis* per unit leaf area (A), and per pustule (B) for six groundnut genotypes.



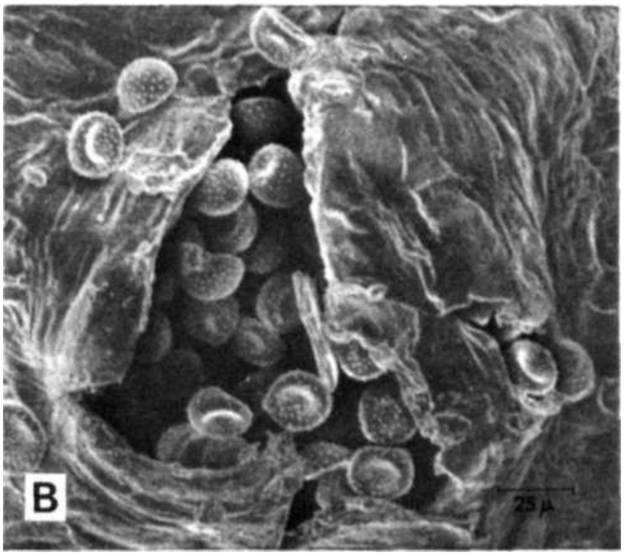


Figure 2. Uredospores of *Puccinia arachidis* on the rust-susceptible genotype TMV 2 (A), and on the rust-resistant genotype NC Ac 17090 (B).

Breeding for rust resistance. In the 1981/82 postrainy and 1982 rainy seasons we made 35 new crosses involving high-yielding lines, rust-resistant advanced breeding lines and germplasm lines to generate rust-resistant, high-yielding populations. In the disease-screening nursery 873 F_2 to F_{10} populations were evaluated. We rejected 133 populations with poor yields and/or high susceptibility to rust, and made bulk selections of the others, which are being advanced in the 1982/83 postrainy season.

Yield trials. Four yield trials comprising F_7 to F_{12} advanced rust-resistant lines, adapted susceptible cultivars, and the rust-resistant parent check NC Ac 17090 were conducted in the 1982 rainy season. Three of the four trials were under both high-fertility and low-fertility rainfed conditions, with and without protection from pests. The other trial was only under low fertility. Several advanced lines outyielded both the susceptible cultivars and the resistant parent under both systems (Tables 6 to 9). The best selections are being evaluated during the 1982/83 postrainy season at Ankola, Karnataka, and Aliyarnagar, Tamil Nadu—to select entries for the Foliar Diseases Resistance Varietal Yield Trial to be conducted through AICORPO during the 1983 rainy season.

Breeding for late leaf spot resistance. During the 1982 rainy season, we raised 14 F_1s from single, triple, and double crosses involving high-yielding advanced lines and lines with resistance

Table 5. Effect of the hyperparasite *Vertcillium lacanii* on development of rust and late leaf spot diseases on groundnut cultivar TMV 2.

Treatment	Rust		Late leaf spot	
	Infection frequency (lesions/cm^2)	Leaf area damage (%)	Infection frequency (lesions/cm^2)	Leaf area damage (%)
Pathogen alone	12.6	19.9	6.7	32.2
Pathogen + *V. lacanii* (mixture)	7.3	8.6	4.5	38.3
Preinoculation with *V. lacanii*	5.3	7.4	3.3	24.5
SE	± 1.27	±1.95	±0.56	±7.33
CV (%)	33.7	36.4	25.9	51.7

Table 6. Breeding groundnut for rust resistance; F_7 and F_8 yield trial, ICRISAT Center, rainy season 1982.

Pedigree	Pod yield (kg/ha)	Haulm weight (kg/ha)	Shelling (%)	100-kernel weight (g)	Reaction[a]	
					Rust	Late leaf spot
(G 37 x EC 76446 (292)) F_7B	2470	3980	65	28.4	2.7	6.7
(DH 3-20 x EC 76446 (292)) F_7B	2320	2930	60	32.3	3.0	7.0
(NC Ac 2190 x NC Ac 17090) F_7B	2260	3090	65	34.9	3.0	7.0
(TG 14 x NC Ac 17090) F_8B	2220	4380	52	29.6	3.0	6.0
(Shantung KU No. 203 x NC Ac 17090) F_8B	1980	3520	56	26.1	3.0	7.0
(JH 89 x NC Ac 17090) F_7B	1970	2990	60	29.3	3.7	7.0
(MH 1 x NC Ac 17090) F_7B	1890	4140	52	30.8	2.7	6.3
(NC Ac 2564 x NC Ac 17090) F_7B	1840	3460	52	28.2	3.3	6.7
(NC 17 x Nc 17090) F_8B	1780	4320	64	24.1	3.0	6.3
NC Ac 17090[b]	1250	3700	59	27.8	2.5	6.3
Robut 33-1[c]	1510	1540	70	31.7	9.0	9.0
JL 24[c]	870	1410	50	22.8	9.0	9.0
J 11[c]	680	1480	65	27.4	9.0	9.0
SE	±140	±239				
CV (%)	16	13				

a. Scored on a 9-point disease scale; 1 = no disease and 9 = 50 to 100% foliage destroyed.
b. Rust-resistant check.
c. Standard susceptible checks.

to both late leaf spot and rust. We will simultaneously screen the F_2s of the crosses for both diseases during the 1983 rainy season.

Genetics of rust resistance. The parents and F_1, F_2, and first backcross generation of both the parents of three resistant lines, PI 259747, EC 76446, and NC Ac 17090 and two susceptible lines, Gangapuri and J 11, were grown during the 1982 rainy season. We recorded rust disease scores and percentages of leaf areas damaged on all plants just before harvest using methods previously described (ICRISAT Annual Report 1981, p. 159). An analysis based on Jinks and Jones' six-parameter model revealed that resistance to rust was predominantly controlled by additive, additive x additive, and additive x dominance gene effects. Duplicate epistasis was observed both for rust-disease scores and leaf-area damage.

Soilborne Fungal Diseases

Pod rot disease. Screening germplasm lines for resistance to pod rot disease continued. Entries showing low pod rot incidence among 213 lines in 1981/82 postrainy-season and 789 in 1982 rainy-season preliminary observation trials are now in advanced screening.

Twenty germplasm lines that had shown resistance to pod rot in earlier trials were grown in replicated field trials with known susceptible genotypes Robut 33-1, TMV 2, M 13, Gangapuri, and EC 76446 (292) in the 1981/82 postrainy and 1982 rainy seasons. Both seasons the trial was repeated on three fields. Mean percentages of pods rotted are shown for each genotype for the three 1981/82 trials in Table 10, and for the three 1982 trials in Table 11. Table 11 also shows pod yields of genotypes from one field in 1982. Most of the genotypes selected as pod rot

Table 7. Breeding groundnut for rust resistance; F_8 yield trials, ICRISAT Center, rainy season 1982.

Pedigree	Pod yield (kg/ha) HF [a]	Pod yield (kg/ha) LF [b]	Haulm weight [c] (kg/ha)	Shelling [c] (%)	100-kernel [c] weight (g)	Reaction [cd] Rust	Reaction [cd] Late leaf spot
(Ah 65 x NC Ac 17090) F_8B	3020	1230	2160	64	34.6	3.0	7.3
(Comet x NC Ac 17090) F_8B_1	2680	1870	2940	64	35.6	3.0	7.3
(GAUG 1 x PI 125974) F_8B	2570	1540	3370	64	25.9	4.5	6.0
(Tifspan x NC Ac 17090) F_8B	2570	1780	3330	62	38.2	3.0	7.0
(Comet x NC Ac 17090) F_8B_2	2450	1630	3140	62	35.5	4.0	7.0
(NC Fla 14 x NC Ac 17090) F_8B	2420	980	3000	53	35.3	3.0	6.3
(TG 14 x NC Ac 17090) F_8B	2410	1220	3100	64	29.2		
(JH 335 x NC Ac 17090) F_8B	2380	1230	2580	60	36.3		
(M 145 x NC Ac 17090) F_8B	2240	1420	2010	64	31.6	3.5	6.8
(JH 171 x PI 259747) F_8B	2200	-	3080	58	25.2		
NC Ac 17090 [c]	1460	1340	4400	60	29.3	2.5	6.3
Robut 33-1 [f]	1350	1280	1640	62	33.5	9.0	9.0
J 11 [f]	1050	-	1700	60	23.5	9.0	9.0
SE	±104	±92	±168				
CV (%)	11	14	11				

a. HF = High fertility with irrigation and protection from insects.

b. LF = Low fertility, rainfed without protection from insects.

c. From HF trial.

d. Scored on a 9-point disease scale; (see Table 6 fn a).

e. Rust-resistant check.

f. Standard susceptible checks.

resistant had significantly fewer (%) pods rotted than the susceptible controls. Several rot-resistant ones had yields as good as the high-yielding control, Robut 33-1.

In the 1982 rainy season seven groundnut genotypes previously selected for pod rot and drought resistance were compared for pod rot resistance with the susceptible genotypes, Robut 33-1 and M 13, in two field trials—one trial on a field in the normal crop rotation; the other on a pod rot sick plot. Pod rot was more severe on plants in the sick plot. Several of the genotypes tested had significantly lower percentages of pods rotted than the checks (Table 12).

The aflatoxin problem. We screened 500 more germplasm lines for dried seeds' resistance to invasion by the aflatoxin-producing *Aspergillus flavus* using techniques previously described (ICRISAT Annual Report 1979/80; 1CRISAT Groundnut Program occasional paper 2), and found no resistant lines.

Genotypes found to resist *A. flavus* invasion of dried seeds in earlier trials were further tested in the 1981/82 postrainy and 1982 rainy seasons and their resistances confirmed. Although percentages of seeds of resistant genotypes colonized by *A. flavus* were low both seasons, percentages were generally lower in seeds from the rainy-season crop than those from the postrainy-season crop, which agrees with results of previously unreported trials in the 1980/81 postrainy and 1981 rainy seasons.

In field trials in the 1981/82 and 1982 seasons we applied inoculum of the toxigenic *A. flavus* strain AF-8-3-2A to the soil around groundnut pods twice, 30 and 20 days before harvest, to study its effects on seed infection and aflatoxin contamination of the seeds. We surface sterilized samples of undamaged, mature seeds and plated them out on Czapek Dox Rose Bengal Streptomycin agar for isolation of *A.flavus.* We tested similar samples of seeds for Aflatoxin B_1 content (Table 13). Pod-soil inoculation significantly increased both seed infection with *A.flavus* and aflatoxin content of seeds. Genotypes differed significantly in *A. flavus* infection and aflatoxin contamination, and the genotype x inoculation-treatment interaction was significant ($P < 0.01$).

In the 1981/82 postrainy season, cultivar TMV 2 was subjected to two irrigation regimes, at 7-day and 15-day intervals. Undamaged mature pods were taken at lifting, and after 24 and 48 hr of windrow drying and tested for aflatoxin content of seeds. Seeds from the 15-day treatment had significantly higher aflatoxin B, contamination than seeds from the 7-day treatment (Table 14).

Breeding for resistance to *A.flavus.* We made 95 crosses involving genotypes resistant to *A. flavus* seed colonization (J 11, UF 71513-1, Ah 7223, Exotic 3-5, U4-4-1, and Var. 27) and high-yielding varieties and breeding lines during the 1981/82 and 1982 seasons.

The *A.flavus* resistant genotypes (PI 337409, PI 337394F, and UF 71513-1) and some of the breeding lines were evaluated for yield potential

Table 8. Breeding groundnut for rust resistance; F_9 yield trials, ICRISAT Center, rainy season 1982.

	Pod yield (kg/ha)		Haulm		100-kernel[c]	Reaction[cd]	
			weight[c]	Shelling[c]	weight		Late
Pedigree	HF[a]	LF[b]	(kg/ha)	(%)	(g)	Rust	leaf spot
(JH 89 x PI 259747) F_9B	3400	-	3130	56	30.2	3.0	7.0
(Var 2750 x PI 259747) F_9B	2700	1460	2800	65	30.8	3.3	6.0
(FSB 7-2 x PI 259747) F_9B	2390	-	3750	59	27.5	3.8	6.5
(Faizpur x PI 259747) F_9B	2380	1390	3350	65	34.4	3.3	6.8
(NC Ac 2190 x PI 259747) F_9B	2310	-	3960	51	25.9	3.3	5.5
(Ah 6279 x PI 259747) F_9B	2200	-	3590	58	30.1	4.3	7.0
(148-7-4-3-12B x PI 259747) F_9B_1	2190	-	3630	60	30.2	3.0	6.3
(148-7-4-3-12B x PI 259474) F_9B_2	2150	1840	3590	50	28.2	4.5	6.3
(Var 2750 x PI 259747) F_9B	2150	1170	3820	56	30.2	4.0	7.0
(X9-2-B-25B x PI 259747) F_9B	2120	1570	2920	65	26.7	3.0	7.0
(Spancross x PI 259747) F_9B	1920	1680	3100	64	28.2	4.0	7.0
(NC Ac 2190 x PI 259747) F_9B	1880	1450	4540	44	26.3	3.3	5.8
NC Ac 17090[c]	1490	1300	5050	60	29.0	2.5	6.4
Robut 33-1[f]	1550	1310	1880	60	32.7	9.0	9.0
JL 24[f]	1370	820	1920	68	36.5	9.0	9.0
J 11[f]	890	490	1850	68	24.5	9.0	9.0
SE	±104	±98	±238				
CV (%)	12	14	15				

a. See Table 7 fn[a].
b. See Table 7 fn[b].
c. From HF trial.
d. Scored on a 9-point disease scale (see Table 6 fn a.)
e. Rust-resistant check.
f. Standard susceptible checks.

Table 9. Breeding groundnut for rust resistance; rust-resistant advanced lines (F_7 to F_{12}) yield trials, ICRISAT Center, rainy season 1982.

Pedigree	Pod yield (kg/ha) HF[a]	Pod yield (kg/ha) LF[b]	Haulm[c] weight (kg/ha)	Shelling[c] (%)	100-kernel[c] weight (g)	Reaction[cd] Rust	Reaction[cd] Late leaf spot
(JH 60 x PI 259747) F_9B	2400	1690	3610	62	32.6	4.8	7.0
(Comet x NC Ac 17090) F_8B	2150	1490	2820	68	31.2	3.3	7.0
FESR 11 (P14)F_{12}B	2140	1670	1780	66	36.7	2.8	5.8
(HG 1 x NC Ac 17090) F_8B	2060	1620	2380	60	24.7	3.3	7.8
(Ah 6279 x PI 259747) F_9B	2050	1550	2820	64	26.8	5.0	7.0
(Faizpur 1-5 x NC Ac 17090) F_8B	1920	1670	3330	60	35.2	3.5	7.3
FESR 11 (P17)F_{12}B	1900	1490	2940	64	35.2	2.3	5.5
(Ah 8254 x PI 259747) F_9B	1760	1490	2690	72	27.3	4.5	6.8
(TG 17 x PI 259747) F_9B	1730	1210	2110	68	33.0	4.3	7.5
(Ah 32 x NC Ac 17090) F_7B	1710	1730	3030	56	28.2	3.5	7.0
(HG 1 x NC Ac 17090) F_8B	1620	1980	2250	50	28.1	3.0	7.3
NC Ac 17090[c]	1420	1230	3840	56	27.0	2.5	6.3
Robut 33-1 *f*	1350	1340	1440	62	32.2	9.0	9.0
J 11*f*	1000	610	1500	56	23.4	9.0	9.0
SE	±125	±73	± 158				
CV (%)	16	11	12				

a. See Table 7 fn a.
b. See Table 7 fn b.
c. From HF trial.
d. Scored on a 9-point disease scale (see Table 6 fn a).
e. Rust-resistant check.
f. Standard susceptible checks.

and resistance during 1981/82 postrainy and 1982 rainy seasons (Table 15). Among the resistant cultivars, UF 71513-1 produced the highest yield both seasons, above J 11, a nationally released cultivar that resists *A. flavus.* Seed colonization percentages were higher for all genotypes in the postrainy season than in the rainy season. Severe rust and leaf spot disease lowered rainy season yields.

Zearalenone in groundnuts. Several species of *Fusarium* commonly associated with rotted pods possess strains capable of producing mycotoxins when growing on suitable substrates under favorable temperature and moisture conditions. We selected seeds from pods with slight pod damage from the ICRISAT 1981 rainy-season crop and tested them for zearalenone. One of 12 samples contained the mycotoxin zearalenone at 1500 µg/kg.

Nematode Diseases

"Kalahasti" malady, a new nematode disease. Collaborating with scientists of the Andhra Pradesh Agricultural University, we investigated a groundnut pod disease in the Kalahasti area of Andhra Pradesh. The disease seems to be restricted to sandy soils and reappears in the same fields whenever groundnuts are grown there. First symptoms to appear, on pegs and developing pods, are small yellowish lesions that darken

Table 18. Incidence of pod rot in groundnut genotypes in field trials, ICRISAT Center, postrainy season 1981/82.

	Pods rotted (%)		
Genotypes	Field 1	Field 2	Field 3
AH 7223	6.2	4.9	3.7
J 11	3.7	3.4	4.6
GFA	5.9	6.7	4.3
#26-5-2	7.4	5.3	4.8
NG 387	6.5	6.5	4.3
C55-437	7.9	6.0	5.4
U-4-4-1	7.1	7.3	6.8
U-4-47-7	7.5	6.6	4.5
NC Ac 664	8.2	8.3	6.2
NC Ac 841	6.0	5.2	3.9
NC Ac 688	6.3	8.4	5.9
Sir of Bizapur	8.1	5.6	4.4
KG 61 240	7.4	8.6	4.3
U-1-2-1	8.3	8.7	5.7
Var. 27	5.9	5.4	4.9
Faizpur	6.0	5.4	3.4
Exotic-6	7.7	6.5	5.0
Local-3	8.4	6.1	5.8
U-2-1-26	8.9	6.8	6.2
Robut 33-1	17.1	19.9	11.6
TMV 2	15.6	15.6	10.6
M 13	19.7	17.5	8.8
Gangapuri	19.3	22.1	16.6
EC 76446 (292)	22.2	27.1	14.8

	SE	CV (%)
For comparison of genotypes in different fields	±1.31	13.9
For comparison of genotypes in each field	±1.28	9.7

and coalesce. Mature pods are small and discolored dark brown (Fig. 3). Shell walls are thinner than normal and kernels are small. We established the disease in the laboratory by growing groundnuts in soil collected from affected fields. We found large populations of the nematode *Tyknchorhynchus brevilineatus* (syn. *T. indicus)* in the soil around diseased pods and established the nematode's pathogenicity by inoculation tests. Preliminary field trials indicate that the disease may be controlled by nematicides.

Virus Diseases

Bud Necrosis Disease

Causal agent. We improved the method of purifying tomato spotted wilt virus (TSWV), the causal agent of bud necrosis disease, and produced an antiserum that gave a titer of 1/250 in precipitin ring-interface tests. In the double antibody sandwich form of the enzyme-linked immunosorbent assay (das-ELISA) the antiserum gave a titer of 1/500 with infected ground-

Table 11. Incidence of pod rot in groundnut genotypes in field trials and pod yields from one field, ICRISAT Center, rainy season 1982.

Genotypes	Pods rotted (%)			Yield of pods (kg/ha)
	Field 1	Field 2	Field 3	Field 3
Ah 7223	5.0	3.8	1.2	1164
J 11	6.6	3.9	1.7	1045
GFA Spanish	6.7	6.4	4.0	896
#26-5-2	6.8	4.9	1.4	1300
NG 387	7.3	4.6	2.4	1291
C55-437	7.3	5.3	2.0	1247
U-4-4-1	7.3	6.0	4.9	859
U-4-47-7	7.7	4.5	2.1	906
NC Ac 664	7.7	9.1	5.3	667
Nc Ac 841	7.8	5.2	2.7	435
NC Ac 688	8.2	10.9	4.4	948
Sir of Bizapur	8.4	6.2	3.3	1330
KG 61-240	8.4	4.5	3.8	1268
U-1-2-1	8.5	7.2	5.9	754
Var. 27	8.7	6.8	5.3	1086
Faizpur	8.9	7.1	4.0	891
Exotic-6	9.8	8.5	3.1	999
Local-3	10.0	9.6	3.7	891
Monir 240-30	10.2	4.7	3.2	605
U-2-1-26	12.4	10.4	7.2	628
Robut 33-1	15.5	15.0	9.9	1001
TMV 2	16.9	16.7	6.4	988
M 13	21.9	16.6	10.1	683
Gangapuri	27.0	23.2	15.7	783
EC 76446 (292)	28.4	18.0	15.2	278
SE		±1.56		±59.24
CV (%)				11.1

nut leaf extracts and 1/10 with healthy plant extracts. Infected mung bean leaf extracts gave a titer of 1/1000 and the serum did not react with healthy mung bean leaf extracts. We adapted the indirect ELISA technique to successfully detect TSWV antigens in groundnut leaf extracts diluted up to 1:1000.

Screening for sources of resistance. In replicated field trials in the 1981/82 postrainy and 1982 rainy seasons at ICRISAT Center, we screened 533 germplasm lines for resistance to bud necrosis disease. Genotypes that showed less than 20% disease incidence in the 1982 rainy-season trial are listed in Table 16 with three commonly grown, susceptible cultivars.

Arachis chacoense (10602) was earlier shown

Table 12. Incidence of pod rot in selected drought-resistant groundnut genotypes and check cultivars in a field trial, ICRISAT Center, rainy season 1982.

Genotypes	Pods rotted (%)	
	Sick plot	Normal plot
EC 102971	3.8	1.3
J 11	4.9	1.4
J 11 x Robut 33-1	4.9	2.2
Virginia Bunch Uranle	6.6	1.4
2-5 x Robut 33-1	8.2	6.9
28-206 x Robut 33-1	9.5	3.9
Manfredi x M 13	12.1	4.0
Robut 33-1 [a]	12.8	9.1
M 13 [a]	15.0	9.0
SE	±1.27	±0.62
CV (%)	25.5	24.9

a. Released cultivars used as drought-susceptible checks.

Table 13. Effects of pod inoculation with a toxigenic strain of *A. flavus* on subsequent levels of seed infection with the fungus and contamination with Aflatoxin B, of groundnut genotypes in field trials, ICRISAT Center, postrainy season 1981/82 and rainyseason 1982.

	1981/82 postrainy season				1982 rainy season			
	Seeds infected with *A. flavus* (%)		Aflatoxin B_1 (µg/kg)		Seeds infected with *A. flavus* (%)		Aflatoxin B_1 (µg/kg)	
Genotypes	Inoc.	No inoc.	Inoc.	No inoc.	Inoc.	No inoc.	Inoc.	No inoc.
PI 337394F	4.3	0.6	9.1	1.0	2.3	0.6	5.2	0.0
UF71513	3.0	0.6	3.0	1.5	1.6	0.0	1.6	0.0
J 11	3.6	0.6	7.0	2.5	2.6	0.0	7.1	0.0
Ah 7223	3.0	0.6	6.6	1.9	1.6	0.0	3.0	0.6
Var. 27	5.6	1.3	14.2	4.0	3.0	0.6	13.9	32.8
Faizpur	-	-	-	-	2.6	0.3	9.9	1.7
C55-437	-	-	-	-	2.0	0.3	3.7	0.0
PI 337409	4.3	1.3	5.5	1.5	-	-	-	-
U-4-47-7	4.3	1.3	4.4	2.0	-	-	-	-
U-4-4-1	6.6	1.0	9.5	0.9	-	-	-	-
U-1-2-1	5.6	1.6	4.2	2.8	-	-	-	-
Exotic 2	5.3	1.6	9.2	3.7	-	-	-	-
Ah 7229	6.3	1.3	7.7	3.1	-	-	-	-
NC Ac 841	6.3	1.3	17.4	1.8	-	-	-	-
TMV 2	7.3	2.3	16.4	6.5	3.6	1.3	21.2	2.5
EC 76446 (292)	10.3	2.6	13.1	4.5	9.6	2.0	32.4	5.6
Gangapuri	13.3	3.6	15.4	3.5	8.6	2.3	27.9	13.4
	SE	CV (%)	SE	CV (%)	SE	CV (%)	SE	CV (%)
For comparison of genotypes	±0.73	24.7	±2.56	50.8	±0.63	36.4	±7.83	111.5
For comparison of inoc. treatments	±0.72	23.8	±2.59	51.6	±0.58	31.5	±7.33	98.5

to resist bud necrosis disease (ICRISAT Annual Report 1981). We examined 100 tetraploid derivatives of crosses involving *A. chacoense* and the cultivated groundnut *Arachis hypogaea* and found all susceptible to bud necrosis disease.

Vector studies. At ICRISAT Center the groundnut crop was invaded by masses of *Frankliniella schultzei,* the vector of TSWV, from mid-August to early September and again from late December to mid-February, confirming information from earlier trials (ICRISAT Annual Report 1979/80; 1981).

Table 14. Aflatoxin B_1 content (µg/kg seed) of seeds of groundnut cultivar TMV 2 grown under two irrigation regimes, ICRISAT Center, postrainy season 1981/82.

		After windrow drying for	
Drought stress regime	At lifting	24 hr	48 hr
Irrigation at 7-day intervals	3.7	3.7	3.5
Irrigation at 15-day intervals	6.2	6.8	7.0
SE	±0.54	±0.24	±0.41
CV (%)	19.0	7.8	13.5

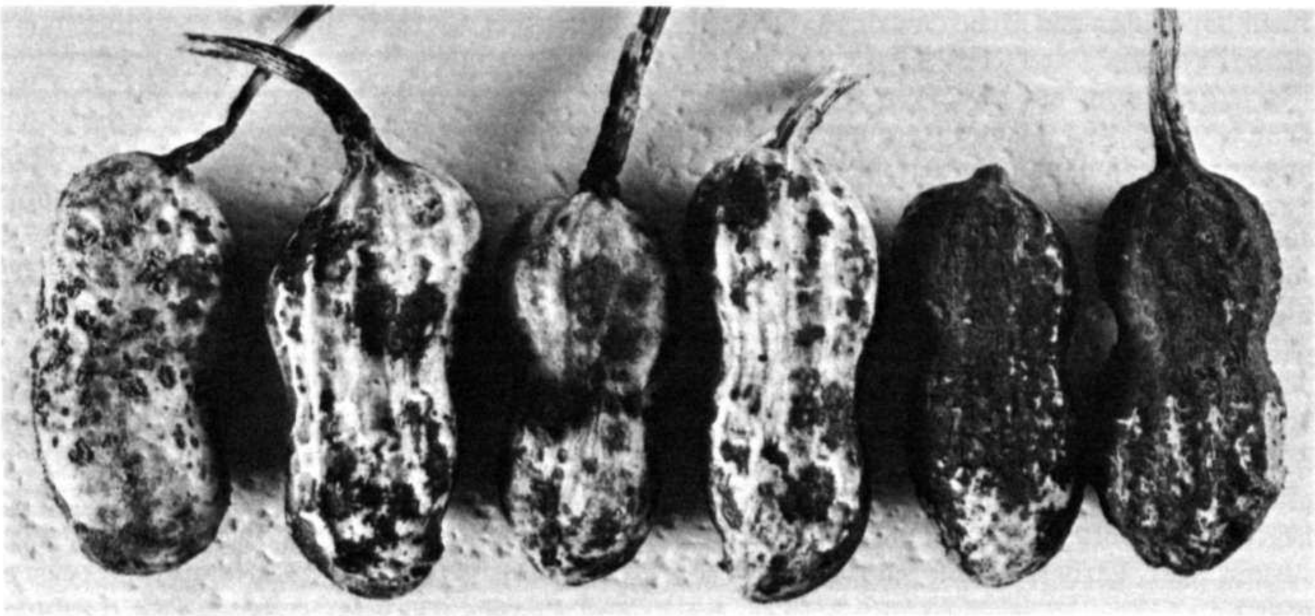


Figure 3. The Kalahasti' malady, a disease caused by the nematode *Tylenchorhynchus brevilineatus,* causes small and discolored pods. Preliminary field trials indicate that nematicides can control the disease.

Table 15. Pod yields, and percentage seed colonization by *A. flavus* in inoculation tests, of selected groundnut genotypes, ICRISAT Center, postrainy season 1981/82 and rainy season 1982.

	1981/82 postrainy season		1982 rainy season	
Genotypes	Yield (kg/ha)	Seed colonization (%)	Yield (kg/ha)	Seed colonization (%)
(Ah 32 x PI 337409) F_7B_1	5920	15.9	1160	11.2
(MGS 7 x PI 337409) F_8B_1	5790	14.6	1220	7.0
(MGS 7 x PI 337409) F_8B_1	5350	17.0	1350	4.8
(NC 17 x PI 337394F) F_9B_1	5440	21.7	1280	8.7
(J 11 x PI 337894F) F_8B_1	5370	21.6	1280	3.8
(Ah 32 x PI 337409) F_8B_1	5250	13.9	1080	9.7
(NC 17 x PI 337394F) F_9B_1	5110	12.0	1420	6.5
(J 11 x PI 337394F) F_8B_1	5040	17.8	1220	5.0
PI 337409 [a]	4260	15.0	1270	7.0
PI 337394F [a]	4640	19.0	940	7.3
UF 71513-1 [a]	5520	16.0	1410	6.5
J 11 [b]	5010	17.0	1170	7.8
Robut 33-1 [c]	4820	55.0	2100	24.0
SE	±297	±2.9	±89	±0.91
CV (%)	10	18	14	20

a. Resistant germplasm lines.
b. National check cultivars.
c. Local check cultivars.

Plant population and disease incidence. Replicated field trials at ICRISAT Center in the 1981/82 postrainy and 1982 rainy seasons again demonstrated that planting groundnuts early and at high population reduced the incidence of hud necrosis disease (ICRISAT Annual Report 1981). In a survey offarmers' groundnut fields in Andhra Pradesh, we noted that hud necrosis was highest where plant populations were lowest, with the incidence ranging from 5 to 20%.

Yield loss from bud necrosis disease. In a field trial at ICRISAT Center in 1982, we tagged groundnut plants infected with bud necrosis. At harvest, we recorded yields of plants infected at various ages. Early infection reduced yields to near zero.

Management of bud necrosis disease. Early planting at high seed rate (ICRISAT Annual Report 1981) again controlled the disease at ICRISAT Center. Preliminary trials also indicated that alternate branched spreading-bunch and prostrate cultivars had lower incidence of bud necrosis disease than sequentially branched upright-bunch cultivars.

Peanut Mottle Virus Disease

Causal agent. The improved das-ELISA technique, which has greater sensitivity in detecting peanut mottle virus (PMV) in groundnut seed, is now used in routine testing for seed transmission. ELISA is also used to test plants in the field.

Screening for resistance. In the 1981 and 1982 rainy seasons and the 1981/82 postrainy season, we screened 496 germplasm lines for resistance to PMV and for percentages of seeds that transmitted the disease. Only 4 lines showed less than 5% yield losses after PMV infection; for most lines losses ranged from 12 to 60%. Those 4 lines with lowest yield losses in preliminary screening

High plant populations and uniform spacing (background) showed low incidence of bud necrosis disease as against plants in foreground, with low density and sparse plant stand. Early planting with a high seeding rate has been shown to control the disease.

were further tested in the 1982 rainy season, with the known PMV-susceptible cultivars TMV 2 and Gangapuri, in a replicated field trial with and without PMV inoculation. Yields of dried pods and estimated yield losses are given in Table 17. Two lines, NC Ac 2240 and NC Ac 2243, had significantly lower yield losses from the disease than two other test lines or the susceptible checks.

Further testing of seed of genotype EC 76446 (292) from PMV-infected plants showed no seed transmission. Genotypes NC Ac 17133 RF and Ah 7171 also showed no seed transmission of PMV when 3000 seeds from infected plants were checked.

Table 16. Groundnut genotypes showing less than 20% incidence of bud necrosis disease in field screening trial, ICRISAT Center, rainy season 1982.

Genotype	ICG No.	Bud necrosis disease[1] (%)
C 136	869	4.5
C 102	848	7.4
Ah 54	504	9.0
C 145-12-P1	2921	10.8
F2 P107 (4) A	-	13.1
NC Ac 2240	5043	13.2
F2 P4(I)	-	13.6
Gujarat narrow leaf	2741	14.6
C 145-12-P-16	884	14.8
NC Ac 1086	1640	15.5
C 156	897	15.7
NC Ac 841	2288	16.4
C 123	2555	17.0
NC Ac 2203	2301	17.3
NC Ac 17888	6317	17.8
NC Ac 1741	5030	18.0
C 121	862	18.1
C 108	2546	18.5
C 125	866	18.8
C 163	902	18.8
NC Ac 1705	6764	19.6
TMV 2[a]	221	91.0
Robut 33-1[a]	799	26.6
M 13[a]	156	46.9

1. Mean of 4 replications.
a. Commonly grown cultivars

Peanut Clump Virus Disease

Causal agent. We have improved the purification of peanut clump virus (PCV) and produced an antiserum that gives a titer of 1/1280 in the precipitin ring-interface test. Immunosorbent electron microscopy (ISEM) has been adapted to detect the virus in crude plant extracts. Using the microprecipitin, das-ELISA, and ISEM tests, we found that the PCV isolates from Ludhiana, India were not related to two PCV isolates from West Africa.

Transmission. The clump virus disease is soil-borne (ICRISAT Annual Report 1978/79). Inoculation tests with possible nematode vectors and the fungus *Olpidium brassica* failed to transmit the disease. The fungus *Polymyxa graminis,* reported vector of PCV in West Africa, was found in all soil samples taken from PCV-infested fields in India; several identified hosts of the fungus are being used in tests to see if *P. graminis* can transmit PCV to groundnuts.

Screening for resistance. Of 1043 lines screened for PCV resistance in naturally infested soils in Ludhiana, Punjab, and Bapatla, Andhra Pradesh, in India, three genotypes (NC Ac 17099, NC Ac 17866, and RG 23 NA 304) have been selected for further evaluation.

Cowpea Mild Mottle Virus Disease

Cowpea mild mottle virus (CMMV) disease has been recorded on groundnut in Maharashtra, Gujarat, and Tamil Nadu States of India, but its incidence is usually low (<1%).

The virus particles are slightly flexuous with a modal length of 610 nm in phosphotungstate (PTA)-stained preparations from crude plant extracts (Fig. 4). Purified virus retained 70% of the infectivity in crude plant extracts. CMMV sedimented as a single component with a sedimentation coefficient of 159 S. The buoyant den-

Table 17. Effect of infection with peanut mottle virus (PMV) on yield of selected groundnut genotypes ICRISAT Center, rainy season 1982.

Genotypes	Yield of dried pods (kg/ha)		Estimated yield loss (%)
	Not inoculated	PMV inoculated	
OG 69-6-1 x PI 259747 F_2. pp. B_1-B_1-B_2-B_2-B_1	901 [a]	731	18.9
Guag 1 x NC Ac 17090 F_2-B_2-B_2-B_1-B_1	1333	1033	22.5
NC Ac 2243	782	696	11.1
NC Ac 2240	1286	1393	None
TMV 2[b]	918	549	40.3
Gangapuri [b]	1007	763	24.2
SE		±133	
CV (%)		30	

a. Mean of 12 replications.
b. Susceptible check cultivars.

sity of purified virus in CsCl was 1.33 ±0.01 g/ml. The virus contained a single polypeptide of molecular weight 33000 daltons and a single ribonucleic acid species of molecular weight 2.6 x 10 daltons, determined in nondenaturing polyacrylamide gels.

Using ISEM, das, and indirect EL1SA procedures, we found CMMV serologically related to carnation latent, potato virus M. chrysanthemum B, hop mosaic, helenium S. and Dulcamara (clevelandii isolate) viruses. It appears that CMMV belongs to the carlaviruses group.

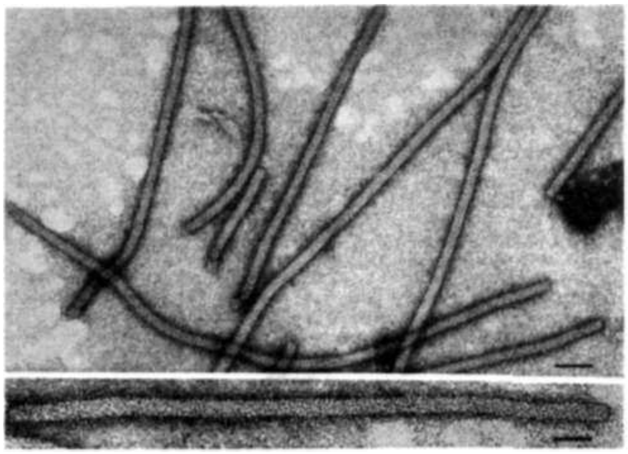


Figure 4. Cowpea mild mottle virus particles: the disease caused by this virus has been recorded in three states of India (Upper bar = 26 nm, lower bar = 46 nm).

Insect Pests

Insect Pest Incidence at ICRISAT Center

We monitored the incidence of insect pests on groundnut in unprotected crops in rainy and postrainy seasons (Fig. 5). Jassids *(Empoasca kerri)* were a major pest in the rainy season; minor pests included thrips (*Scirtothrips dorsalis* and *Frankliniella schultzei),* leafminer *(Aproaerema modicella),* tobacco caterpillar *(Spodoptera litura).* and bollworm *(Heliothis armigera).* Leafminer infestations were high during dry spells in August but declined rapidly after heavy rains in September and October. White grub *(Lachnostema fissa)* caused extensive damage in localized patches, particularly in fields close to host plants for the adult beetles, such as neem *(Azadirachta indica),* and *Casuarina equisetifolia.* The pod-sucking bug, *Elasmolomus sordidus,* infested pods in windrows and in storage.

In the postrainy season, leafminers and tobacco caterpillars were the major pests, and thrips were minor pests.

Populations of male moths of *Spodoptera litura* were monitored with sex pheromone traps.

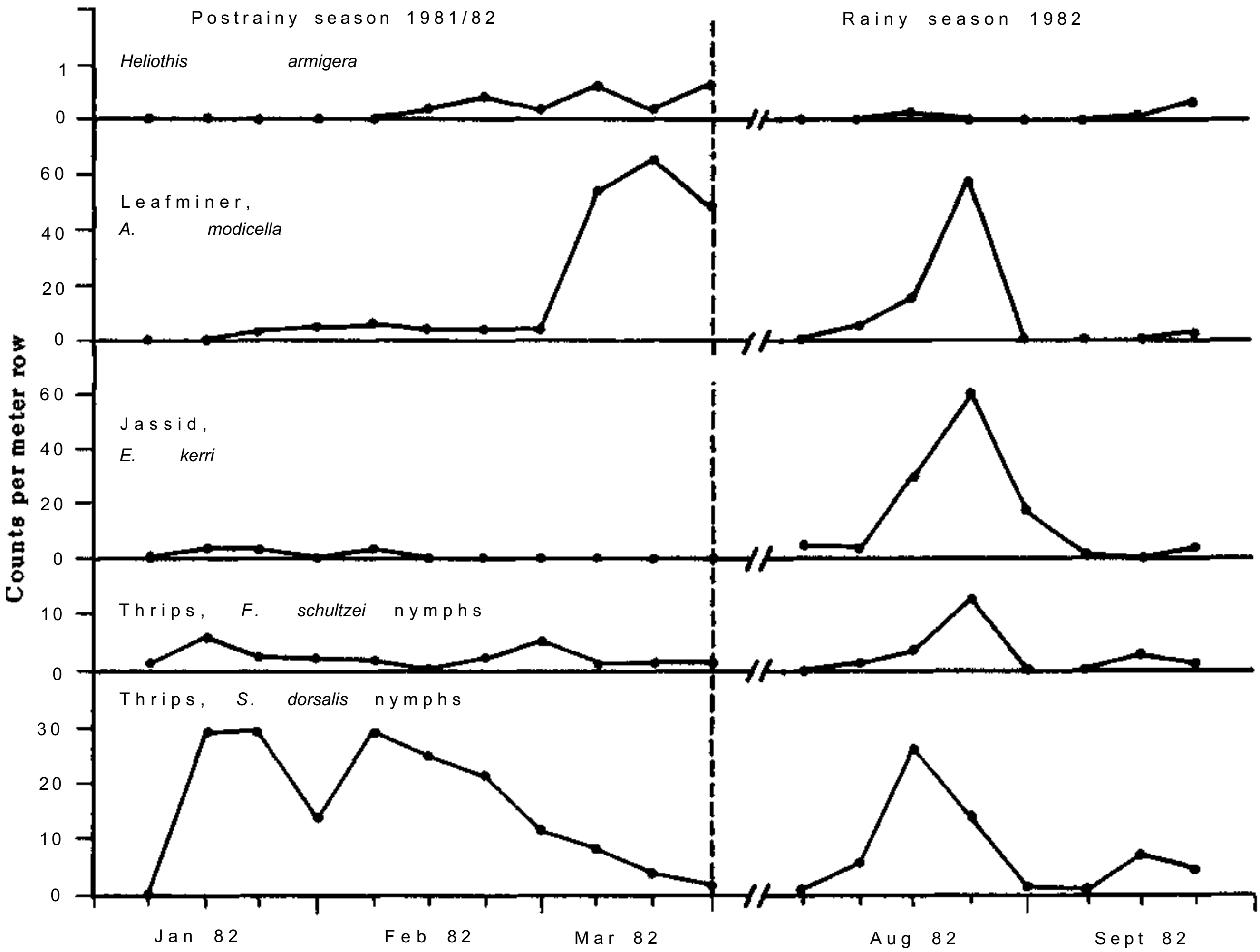


Figure 5. Pest incidence at ICRISAT Center, during indicated months of postrainy season 1981/82 and rainy season 1982.

Traps 80 and 150 cm above ground caught more moths than traps 200 cm above. The pheromones' effectiveness declined after 4 weeks' exposure.

Population changes in male leafminer moths were recorded by using sticky traps baited with virgin females (ICR1SAT Annual Report 1981) in a few fields (Fig. 6). In the postrainy seasons leafminers were abundant from March onwards in both 1981 and 1982. In the 1982 rainy season the insect completed four overlapping generations.

Pest Surveys in India

Several surveys were carried out. In Andhra Pradesh, leafminer was a major pest in the rainy season in Mahbubnagar, Kurnool, Anantapur, and Nalgonda districts. The first three of those districts suffered a dry spell during August and part of September. In the postrainy season, tobacco caterpillars devastated groundnut and other crops in Prakasam, Nellore, Chittoor, and parts of Anantapur districts. Severe damage by thrips, *F. schultzei,* was observed in some groundnut fields in Prakasam district. Leafminer was a major pest in Nasik and Sholapur districts of Maharashtra during July 1982.

Yield Losses Associated with Insect Pests at ICRISAT Center

Two trials were conducted in the 1981/82 postrainy season and two in the 1982 rainy season.

The tobacco caterpillar, Spodoptera litura, is a major insect pest of groundnut grown in the postrainy season in Andhra Pradesh, Tamil Nadu, and Karnataka.

In the postrainy season yield losses were not significant, probably because leaf miner (the major pest) infestations occurred near crop maturity, and infestations by *Spodoptera litura* were negligible. In the rainy season, however, pest control increased yields of both pods and haulms.

Table 18. Effect of pest control on yield of groundnut cv TMV 2, ICRISAT Center, rainy season 1982.[1]

Treatment	Plant population/plot	Haulm weight (kg/ha)	Pod weight (kg/ha)
Not protected	1113	2970	1290
Fully protected	1108	3620	1410
SE		±57.9	±37.9
CV (%)		6.6	10.5

1. Mean of 14 replications.

In one experiment, yields of plots protected throughout the season increased 9% in dry pod weight and 22% in haulm weight (Table 18). Jassids were the major pests. In a second trial in another field, plots were protected for different durations. Yield increases were 32% in plots protected from emergence till maturity, 55% in plots protected from 45 days after emergence, and 20% in plots protected from 85 days after emergence (Table 19). The major pests were thrips, leafminer, *Heliothis,* and *Spodoptera.*

Pest Management

Cultural Practices

Effect of plant stand on insect infestation. We used three commonly grown groundnut cultiv-

Table 19. Insect-pest damage and pod yield in groundnut (cv Robut 33-1) ICRISAT Center, rainy season 1982.

Treatment[1]	Leaflets damaged (%)[2]				Pod yield (kg/ha)
	Leafminer	*Heliothis*	Thrips	Jassids	
Fully protected	2.3	16.2	3.9	1.6	1140
Protected from 45 DAE	12.8	16.0	7.6	13.2	1340
Protected from 85 DAE	14.7	16.3	9.1	14.4	1040
Unprotected	15.3	17.7	9.1	14.6	860
SE					±51
CV (%)					9.3

1. Protection with sprays of monocrotophos (0.1%) at 10-day intervals.
2. Mean of 4 replications - size of sample = 25 plants per replication; date of sampling = 27 August.
DAE = days after emergence.

ars, TMV 2 (upright-bunch), Robut 33-1 (spreading-bunch), and M 13 (prostrate plant habit) in 10 m x 8 m plots with four replications in the 1981 rainy season in a pesticide-free, low-fertility field. Two spacings were used: 75 cm between rows and 15 cm between plants, and 30 cm between rows and 10 cm between plants. Insect infestations were recorded weekly on 10 randomly-selected plants per plot (Table 20). Infestations of thrips, jassids, and leafminers were lower on closely spaced than on widely spaced plants. TMV 2 showed large infestation differences between spacing treatments mainly by thrips *(Scirtothrips dorsalis),* jassids, and leafminers, Robut 33-1 and M-13 showed thrips and leafminer differences. Jassid infestation was lowest in M-13; leafminer infestations were similar in all three genotypes.

Pest incidence in intercropped groundnut. In collaboration with the Farming Systems Research Program (FSRP), groundnut (cv TMV 2) was intercropped with pearl millet (hybrid BK 560), sorghum (hybrid CSH-6), maize (hybrid Deccan), pigeonpea (ICP-36-6), sunflower (cv Morden), and castor (cv Aruna). Rows were 30 cm apart, plants 10 cm for groundnut, 20 for maize, 15 for sorghum, 30 for pigeonpea, 10 for sunflower, and 20 for castor. Plots were 25 m x 15 m with 3 replications separated by 30 m of unsprayed groundnut crop. Cereals were sown 1 row after 3 rows of groundnut; other crops, 1 row after every 5 rows of groundnut. Data on pest incidence are shown in Table 21.

Thrips, jassid, and leafminer infestations were lowest in groundnut intercropped with pearl millet.

Insecticides

In laboratory tests, 4- to 17-day-old tobacco caterpillars *(Spodoptera litura)* were fed ground-

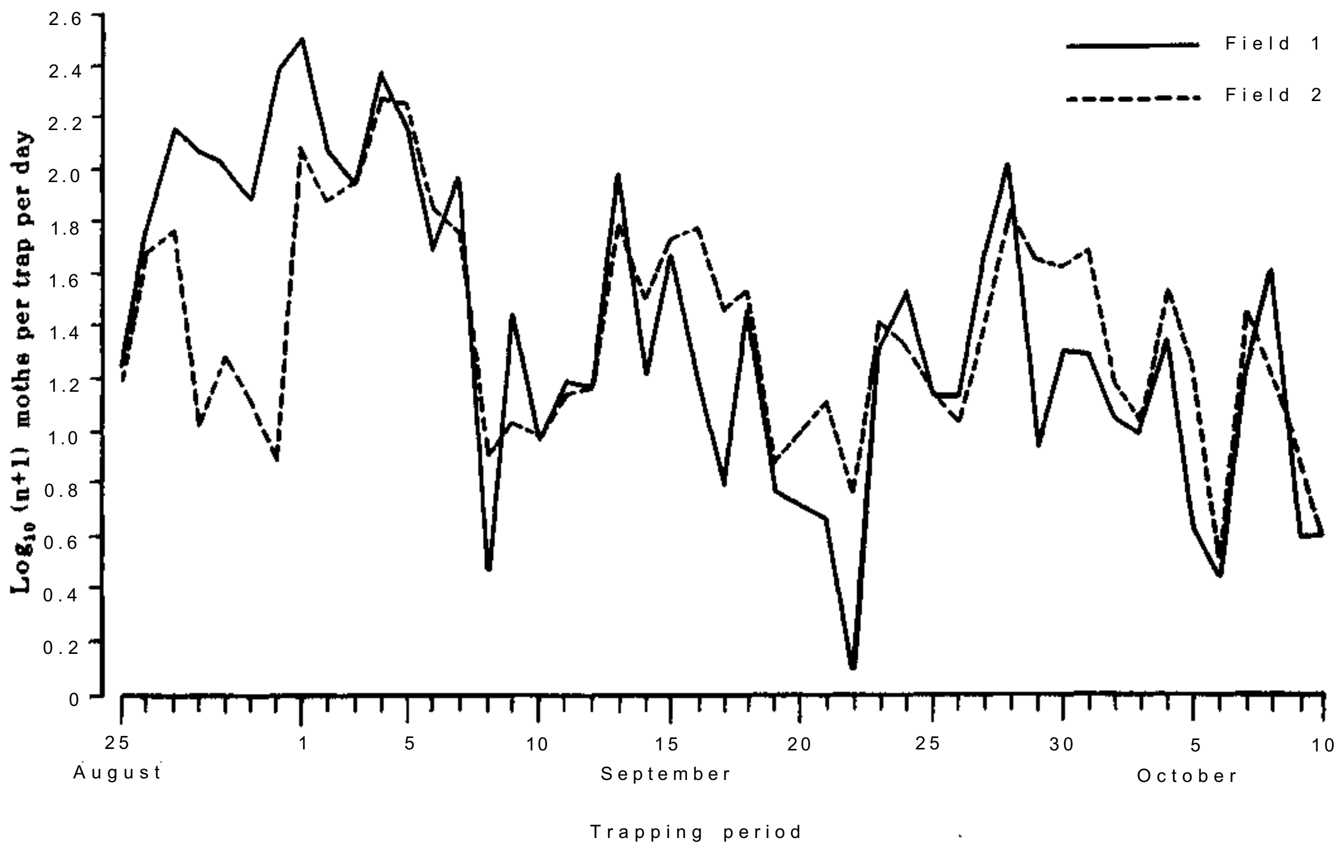


Figure 6. Numbers of leafminer *(Aproaerema modicella)* moths caught in virgin female-baited sticky traps in two fields at ICRISAT Center, rainy season 1982.

Table 29. Effect of row and plant spacing on pest infestation[1] in selected groundnut genotypes, (plot size = $80 m^2$) ICRISAT Center, rainy season 1981.

	Spacing		Thrips					
	Between rows	Between plants	*S. dorsalis*		*F. schultzei*		Jassid	Leafminer
Genotype	(cm)	(cm)	Adults	Nymphs	Adults	Nymphs	nymphs	mines
TMV 2	30	10	22	40	15	8	19	115
	75	15	53	86	19	16	35	196
Robut 33-1	30	10	12	29	7	4	19	109
	75	15	30	65	5	7	19	211
M 13	30	10	14	26	7	1	12	113
	75	15	21	45	4	1	13	221
Mean			25.4	40.5	9.4	6.2	19.5	160.9
SE			±5.6	±13.6	±3.4	±1.6	±3.5	±20.7
CV (%)			44	41	71		36	21

1. Observations were taken on 10 randomly-selected plants in a plot at peak infestation.

nut leaves sprayed with different insecticides. Methomyl (at 0.05% and 0.1% concentration) killed the most.

Host Plant Resistance

Jassids

We screened 403 genotypes and breeding lines for resistance to jassids in replicated field trials in the 1982 rainy season at ICRISAT Center using techniques described in ICRISAT Annual Report 1981 (p. 179). Resistance previously reported in several lines was confirmed, and some resistance was found in several rust-resistant genotypes and breeding lines (Table 22).

Three lines, NC Ac 16940, K-4, and NC Ac 2142, had heavy jassid infestations but showed little yellowing. Genotypes NC Ac 16940 and

Table 21. Pest incidence in intercropped groundnut, (groundnut was the main crop in each case), ICRISAT Center, rainy season 1982.

	Pest incidence[1] at peak infestation[2]			
	Thrips			
	S. dorsalis	*F. schultzei*	Jassid	Leafminer
Intercrop	nymphs	nymphs	nymphs	mines
Sole groundnut	13.9	0.8	60.5	58
Pearl millet	9.9	0.1	32.6	22
Sorghum	15.0	0.3	57.1	44
Maize	17.3	0.7	50.5	37
Pigeonpea	17.3	1.0	60.8	51
Sunflower	21.8	0.7	66.9	47
Castor	19.8	0.1	73.5	32
SE	±2.0	±0.2	±5.0	±6.0
CV(%)	21.0	56.0	15.2	24.7

1. Counts per meter row.
2. Thrips, last week of August: jassids, first week of September; leafminer, last week of September.

Table 22. Sources of resistance to jassids in selected groundnut genotypes, ICRISAT Center, rainy season 1982.

	Set 1 (111 entries)		Set 2[a] (79 entries)		Set 3 (213 entries)	
Genotype	Yellowed foliage (%)	Jassid nymphs per 5 plants	Genotypes	Yellowed foliage (%)	Genotype	Yellowed foliage (%)
NC Ac 2243 (T)	0.03	20	ICG 6322[b]	5.0	NC Ac 2230	0.1
NC Ac 2230	0.07	2	NC Ac 2750		75-83[b]	4.3
NC Ac 2232	0.10	17				
NC Ac 2242	0.20	17	PI 259747[b]	8.0		
K-4	0.40	49				
NC Ac 2240 (T)	0.40	36	TMV 2	60.0	TMV 2	56.7
NC Ac 16940[b]	0.40	53				
NC Ac 2243 (pp)	0.70	9				
NC Ac 2240[b] DP)	1.40	16				
Gujarat narrow-leaf[b]	2.00	4				
NC Ac 1705	3.70	18				
NC Ac 2142	4.70	48				
NC Ac 343	6.80	26				
M 13[c]	8.00	15				
Robut 33-1[c]	33.30	34				
TMV 2[c]	43.30	103				

a. Rust resistant entries.
b. New entries found less susceptible to jassids.
c. Check cultivar.
T = Tan testa.
DP = Deep purple testa.

K-4 have dark green foliage; genotype NC Ac 2142, dark green corduroy-like foliage.

Screening progenies of jassid-resistant genotypes. Seventy-six progenies from crosses between high-yielding cultivars and jassid-resistant cultivars NC Ac 2214, NC Ac 2232, and NC Ac 343 were screened in a replicated field trial in the pesticide-free area, with laboratory-bred jassids released to increase the infestation. Fifteen progenies in F_4 to F_6 generations showed some resistance to jassids (Table 23).

Survival of jassid nymphs on resistant cultivars. Survival of jassid (*E. kerri*) nymphs was tested on cultivars that resisted them in field trials. Three shoots of each cultivar from field-grown plants were placed in moist sand in 5 cm x 8 cm plastic jars with tight-fitting lids. The nymphs required high humidity inside the jars to survive more than 5 days on susceptible cultivars; most nymphs in jars without a lid died within 2 days. Ten second-instar nymphs were released on each plant's foliage. All nymphs released on NC Ac 343, NC Ac 2230, and NC Ac 2242 were dead by day 4 (Table 24). The least died on Robut 33-1. Nymphs on field-resistant cultivars had higher mortality than those on susceptible cultivars.

The hairy leaves of cultivar NC Ac 2230 hindered feeding and movement of young nymphs.

Thrips

We screened 58 genotypes in the field for resistance to thrips *(Frankliniella schultzei),* scoring injury on a 1-9 scale and counting leaflets with thrip injury (Table 25). NC Ac 2240 had the least damage with a mean score of 3.2 and only 2%

leaflets damaged; check TMV 2 was rated 9 with 19% of its leaflets damaged.

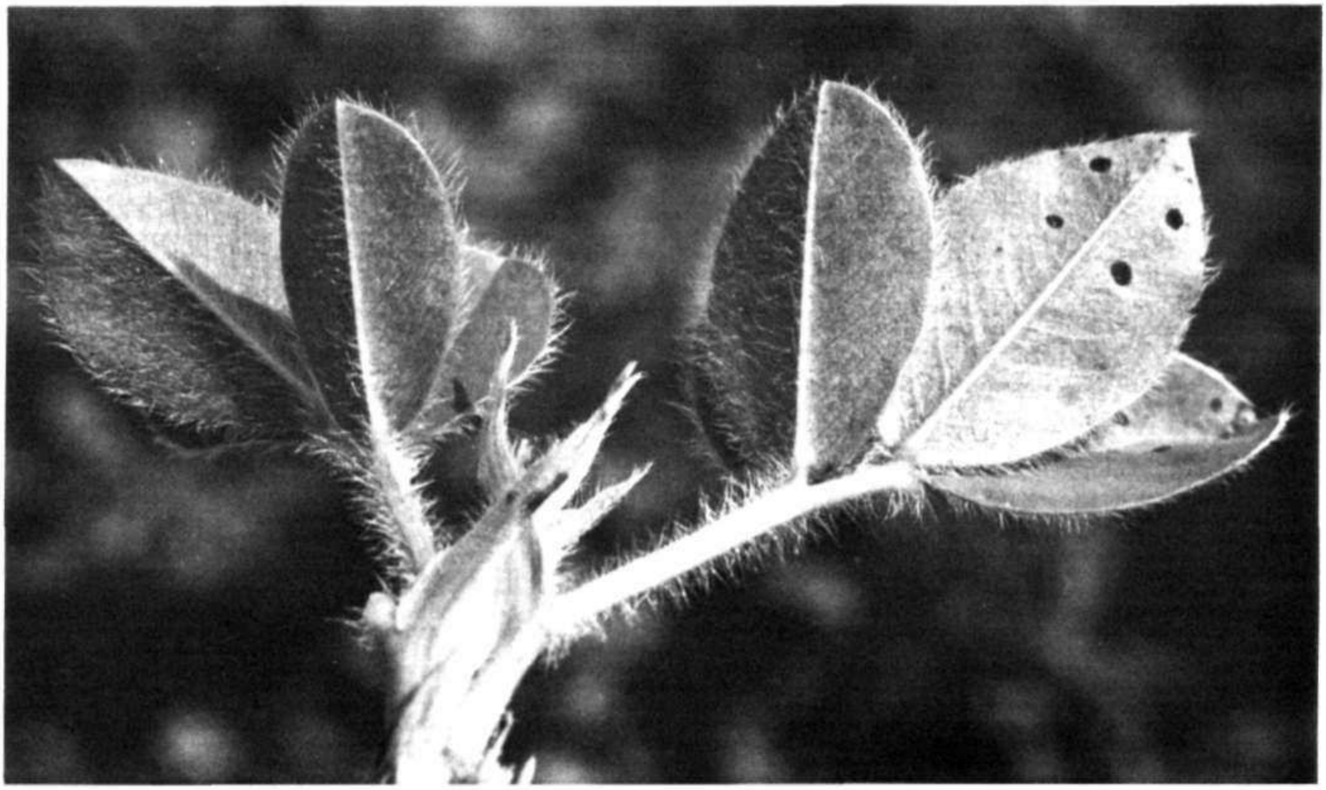
We also scored thrips injury on a 1-9 scale on 262 genotypes in a pesticide-free Alfisol field. Five erect-bunch entries (HUA-113, PI 261945, PI 314817, NC Ac 16058. RV-11), five spreading-bunch entries (NC Ac 1705, 309/75, NC Ac 2123, M-302-73, and Ku 19), and five runner entries (VRR 170, VRR 265, VRR 257, NC Ac 2891, and VRR 198) showed resistance.

Laboratory screening of wild *Arachis* species. We assessed survival and fecundity of *F. schnitzel* on detached leaves of eight wild *Arachis* species in a growth chamber with 12-hr day (at 28°C) and 12-hr night (at 21°C). The thrips' survival and fecundity were considerably reduced on some wild species; survival was lowest on *A. chacoense,* and fecundity was zero on *A. batizocoi, A.villosa,* and *A. currentina* (Table 26).

In many wild species survival of thrips was adversely affected. This could have resulted in low fecundity. To see if the resistance stemmed from decreased feeding or oviposition, we provided a supplementary diet of pollen to assure normal survival. Then, with no resistance to oviposition, fecundity would increase. On each wild species, we released thrips in one set on leaves alone and in the other set, on leaves and pollen for 3 days, then transferred surviving thrips to the same dietary regime as TMV 2—to see if thrips used in these tests could oviposit. On some wild *Arachis* fecundity increased substantially when survival increased. On others, such as *A. chacoense,* fecundity was increased only marginally even though survival was normal, so *A. chacoense* may resist feeding and oviposition. The resistance may be incorporated in future groundnut cultivars.

Aphids

We screened more than 600 genotypes for resistance to aphids *(Aphis eraccivora)* in the screen-



Hairiness of leaves and petioles—as in this groundnut cultivar NC Ac 2230—has been found to reduce infestation of jassids by hindering the feeding and movement of nymphs.

Table 23. Jassid damage (% yellowed foliage) in some groundnut breeding material, ICRISAT Center, rainy season 1982.

Pedigree	Yellow foliage[1] (%)
(M 13 x NC Ac 2214) F_3-B_0-B_1 (S VR R)-B_2-H_1	2.3
(Robut 33-1 x NC Ac 2214) F_3-B_1-B (T VR Ta) B_2-H_1	3.3
(Robut 33-1 x NC Ac 2214)F_3-B_0-B_1 (R VR Ta) B_2-H_0	5.0
(Colorado Manfredi x NC Ac 343) F_2-B_1-B_1-B_1 (Ta)	5.7
(M 13 x NC Ac 2214) F_3-B_1-B_1 (S VB Ta) B_2-H_0	6.0
(M 13 x NC Ac 2214) F_3-B_0-B_1 (R VR DP) B_2-H_1	6.7
(NC Ac 2232 x Gangapuri) F_2-B_1-B_1-B_1	6.3
(Robut 33-1 x NC Ac 2214) F_3-B_2-B_1 (R VB Ta) H,	7.3
(Robut 33-1 x NC Ac 2214) F_3-B_1-B_1 (T VBTa) B_2-H_2	7.3
(JL 24 x NC Ac 2214) F_2-B_1-B_1-B_1-H_1	8.7
(MK 374 x NC Ac 2214) F_2-B_1-B_1-B_2-H_1	9.0
(M 13 x NC Ac 2214) F_3-B_1-B_1 (S VB P) B_2-H_0	10.0
(M 13 x NC Ac 2214) F_3-B_0-B_1 (T VB Ta) B_2-H_0	10.7
(Manfredi x NC Ac 343) F_2-B_1-B_1P	12.3
(Manfredi x Nc Ac 343) F_2-B_1-B_1 (Ta)	12.7
TMV 2 (check)	43.3

1 = Mean of 3 replications

house, by releasing from 20 to 30 adults and nymphs on each plant. After 15 days, all plants with fewer than 25 aphids were reinfested. None of the genotypes resisted the aphids.

Leafminer

Preliminary screening for leafminer resistance was started with 186 genotypes in the 1980/81 postrainy season. In the 1981/82 postrainy season, we screened 800 genotypes. Damage was recorded on a 1-9 scale (1 = no damage; 9 = severe damage). No test entry was resistant but some suffered less damage than the controls. In the upright-bunch cultivars, the best selections scored 7.0 to 7.5 compared with 8.2 for TMV 2; in spreading-bunch cultivars, the best scored 6.3 to 7.5 compared with 8.6 for Robut 33-1, and in the runners, the best selection scored 6.6 to 7.2 compared with 8.1 for M 13. Selected genotypes are being retested.

Heliothis armigera

We screened genotypes against *Heliothis* in the 1982 rainy season. Infestation was low, but no entry was free from attack. A few genotypes with less leaf damage than the standard susceptible checks (Table 27) are being tested further.

Termites

We sowed 113 genotypes, including lines that in 1981 showed low pod scarification, in a replicated trial in a termite-infested, Alfisol field in the pesticide-free area. Uniform termite infestation was encouraged by avoiding deep cultivation, providing sawdust in the summer months, collecting mating pairs during June, and redistributing them in the field.

Table 24. Survival of jassid nymphs on detached shoots of resistant and susceptible groundnut genotypes.

Genotypes	Foliage	Mean % nymphs surviving after 96 hr
Robut 33-1 (Check)	Normal	40
NC Ac 1705	Thick	23
NC Ac 2144	Corduroy	20
NC Ac 2154	Corduroy	13
NC Ac 2240(T)	Normal	10
M 13	Normal	10
NC Ac 2240(DP)	Normal, pigmented	7
NC Ac 2243(DP)	Corduroy, thick, pigmented	3
Nc Ac 2243(T)	Corduroy, thick	3
NC Ac 2232(Q)	Corduroy, thick	3
NC Ac 343	Normal	0
NC Ac 2230	Thick, hairy	0
NC Ac 2242	Corduroy, thick, hairy	0
Mean		9.7
SE		±5.1
CV(%)		11.3

Arcsin transformation before analysis.

Table 25. Resistance of groundnut genotypes to thrips, ICRISAT Center, postrainy season 1981/82.

Genotype	Leaflets damaged (%)	Thrips injury 1-9 scale[1]
NC Ac 2240(DP)	2.0	3.2
NC Ac 2243 (T)	2.0	3.6
NC Ac 2243(DP)	2.2	3.8
NC Ac 2242	3.0	3.6
NC Ac 2142	4.7	4.6
NC Ac 2154	4.7	6.0
NC Ac 2230	5.3	6.4
NC Ac 343	5.6	8.4
NC Ac 16940	6.2	4.0
NC Ac 2232	6.4	4.6
TMV 2[a]	19.0	9.0
Robut 33-1[a]	13.4	8.2
M 13[a]	18.6	7.0

1. I = no damage; 9 = severe damage.
T = Tan testa.
DP = Deep purple testa.
a. Commonly grown cultivars.

The plants were harvested 1 month after normal maturity when we rated pods for termite damage on a 1-9 scale (1 = no scarification; 9 = total scarification).

Table 26. Survival and fecundity of *F. schultzei* on some *Arachis* spp.

Arachis spp.	Mean survival (days)	Mean fecundity per female[1]
A. chacoense	3.7	2.0
A. batizocoi	4.0	0.0
A. correntina	4.5	0.0
A. villosa	4.7	0.0
A. pusilla	5.7	2.4
A. glabrata	6.0	4.0
A. duranensis	6.4	2.0
A. sp. PI 10596	8.0	5.0
A. hypogaea cv TMV 2	8.7	12.2

1. Number of nymphs per female. The experiment was conducted by caging five *F. schultzei* on a single leaflet in small glass vial kept at 28°C from 0600 to 1800 hr, and at 21°C from 1800 to 0600 hr. The leaflets were changed every day.

Resistance of several genotypes selected from the 1981 trial was confirmed, and a few more showed low resistance (Table 28). Some genotypes NC Ac 2243(T) and NC Ac 2240 had few scarified pods and low injury ratings for the few damaged pods. Others (C-5, NC Ac 2232 and NC Ac 7663) had few damaged pods but high injury to individual pods. We are investigating possible causes for the variation and the basis of termite resistance.

Breeding for Pest Resistance

Five cultivars with varied resistance to jassids, thrips, and termites (NC Ac 343, NC Ac 1705, NC Ac 2232, NC Ac 2240, NC Ac 2242) and breeding lines derived from Robut 33-1 x NC Ac 2214 (resistant to jassids and with better plant type than NC Ac 2214), were crossed with high-yielding varieties and breeding lines. Three with

Table 27. Leaflet damage by *Heliothis armigera* to selected groundnut genotypes, ICRISAT Center, rainy season 1982.

Genotypes	Mean no. of leaflets damaged (%)	
C-112	7.8	(15.57)[a]
2957	7.8	(16.22)
C-98	8.2	(16.58)
NC Ac 2240	9.7	(18.02)
M 145	9.9	(18.28)
TMV 8	10.4	(18.65)
Robut 33-1[b]	14.7	(22.50)
M 13[b]	17.2	(23.93)
TMV 2[b]	27.6	(31.53)
NC Ac 927	31.5	(34.00)
NC Ac 17127	33.1	(35.09)
NC Ac 16074	33.4	(35.27)
SE		±(2.26)
Mean of 64 genotypes	19.6	(25.81)
CV (%)		(12.40)

a. Figures in parentheses are arcsine square root transformed values.
b. Standard commercial cultivars.

Table 28. Groundnut genotypes showing low pod scarification by *Odontotermes* sp., ICRISAT Center, rainy season 1982.

Genotype	Number of pods scarified (%)	Scarification rating on 1-9 scale[a]
NC Ac 2243 (T)[b]	0.5	4.7
NC Ac 2240 (T)[b]	0.5	4.0
NC Ac 2242[b]	3.1	4.9
NC Ac 2690	4.2	2.6
C-5	5.5	6.8
NC Ac 2240 (DP)[b]	5.7	5.8
NC Ac 2575	7.6	6.9
NC Ac 17587	7.6	6.6
NC Ac 7663	7.7	7.7
NC Ac 2232	7.8	7.3
NC Ac 2891	7.9	6.6
FESR 386	7.9	7.6
NC Ac 1122	8.8	7.0
NC Ac 10033[b]	9.3	6.6
FESR 108	9.9	4.8
TMV 2[c]	25.1	7.0
Robut 33-1[c]	44.4	6.8

a. 1 = no damage; 9 = heavy damage.
b. Promising in 1981 trial.
c. Commonly grown cultivars.
T = Tan testa.
DP = Deep purple testa.

little pod scarification from termites during 1981 rainy season (NC Ac 1113, NC Ac 10033, and FESR 2-P5-P3-P2-B1) were also crossed with high-yielding genotypes. Such crosses totalled 150 the last two seasons.

Screening breeding material for resistance to jassids. Selections in advanced generations, mainly derived from NC Ac 343, NC Ac 2214, and NC Ac 2232 crosses, were evaluated for jassid resistance in a pesticide-free Alfisol field during the 1982 rainy season. The jassid population was manipulated by planting cowpeas in infester rows after every five test rows; 35 selections resistant to jassids and with good agronomic characters were identified for further testing.

Nitrogen Fixation

Response to *Rhizobium* Inoculation

Evaluation of *Rhizobium* strains. When selecting *Rhizobium* strains for use in inoculants, it is usual to first evaluate their nitrogen-fixing capability in sterile media under controlled conditions without any mineral nitrogen addition. During 1982 we compared the performance of 19 strains as inoculants for groundnut grown in an initially sterilized, sand: vermiculite root medium in the glasshouse with their performance in an Alfisol field during the rainy season. The field soil contained an indigenous population of *Rhizobium* capable of nodulating groundnut. For traits associated with nitrogen fixation there was no significant $(P < 0.05)$ correlation between the two environments (Table 29).

The nitrogen content of plants grown without mineral nitrogen indicates effectiveness in N_2-fixation of the *Rhizobium* strains. However, total N in the plants grown under N-free conditions was poorly correlated (r = 0.19) with the pod yields obtained in the field. The strain NC 43.3 ranked highest in N_2-fixing efficiency on cv Robut 33-1 in the glasshouse experiment, but did not significantly increase pod yield of this cultivar in the field beyond that ofthe noninocu-

Table 29. Correlation between glasshouse and field observations of traits associated with N_2-fixation in groundnut.

Traits[1]	Correlation coefficient (df = 17)
Nodule number	0.37
Nodule weight	-0.25
Plant top weight	0.10
Nitrogenase activity (μmoles C_2H_4/plant per hr)	0.35

1. Observations were recorded 30 days after sowing in the glasshouse and 64 days after sowing in the field trial.

lated plants (Fig. 7). Strain NC 92, which has a high rank in the glasshouse test gave the largest increase in pod yield in the field (Fig. 7). These results indicate that N_2-fixation under controlled conditions should not be used as the sole criterion for selecting *Rhizobium* strains for use in field inoculation trials, and that the competitive ability of the strains should be evaluated; we are examining methods for testing this in the glasshouse. However, the most efficient way to test for competitive ability is to conduct a field trial of potential inoculant strains.

Field response to *Rhizobium* inoculation. In our previous field trials, we have shown that the advanced cv Robut 33-1 responds to inoculation with *Rhizobium* strain NC 92 (see ICRISAT Annual Report 1981, pp. 183-184). During the 1982 rainy season we observed that two other cultivars JL 24—currently in minikit trials prior to national release, and ICGS 27—an elite line bred at ICRISAT—also gave higher yields when inoculated with the strain NC 92 (Table 30).

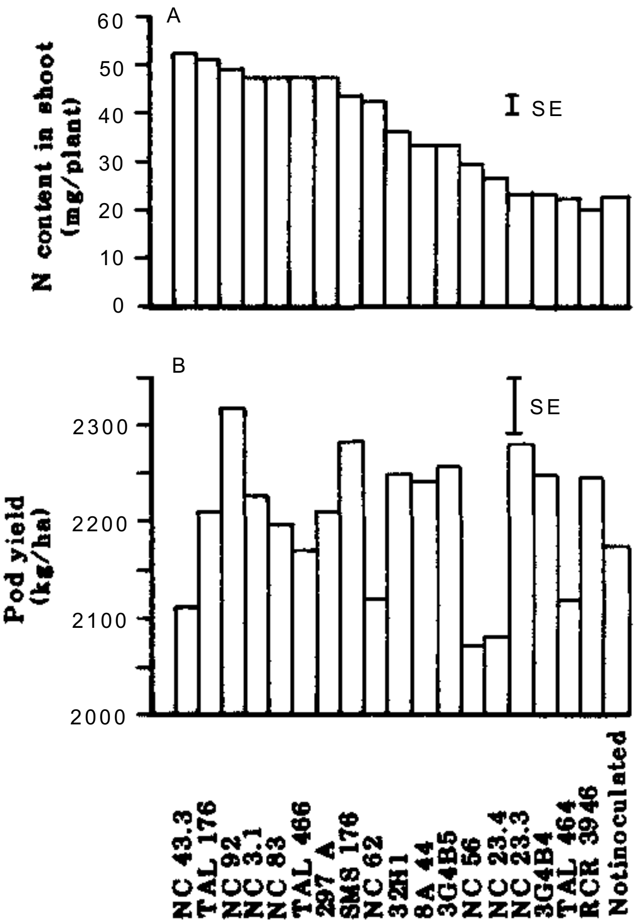


Figure 7. Comparative evaluation of *Rhizobium* strains for nitrogen-fixing efficiency in the glasshouse (A), and their effect as inoculants on pod yield in the field (B) of cv. Robut 33-1, ICRISAT Center, rainy season 1982.

Table 30. Response of groundnut yield (kg/ha) to *Rhizobium* inoculation, ICRISAT Center, rainy season 1982.

Treatment	JL 24	ICGS 27	Robut 33-1	Mean
NC 92	1580	1750	1750	1700
Not inoculated	1490	1580	1650	1570
SE		±60		±35
Mean	1550	1670	1700	
SE		±43		
CV (%)		7.4		

Use of ELISA to identify strains. We have successfully used the ELISA (Enzyme Linked Immunosorbent Assay) technique to assess the success of the *Rhizobium* inoculum strain NC 92 in forming nodules on groundnuts in an Alfisol field containing a large native population of *Rhizobium* (10^2 -10^4/g soil) capable of nodulating groundnut. Individual nodules from test plants were examined by ELISA to see if they reacted with antisera produced against strain NC 92. Data from field experiments in the 1981 and 1982 rainy seasons indicated that strain NC 92 used alone as the inoculant formed 25 to 30% of the total population of nodules on cv Robut 33-1 (Tables 31 and 32). Strain NC 92 when used as an inoculant for field sowings has consistently increased the pod yield of cultivar Robut 33-1 (see ICRISAT Annual Report 1981, pp. 183-184). The season had a marked effect on the response of different cultivars to inoculation. Cultivar ICGS 15, a selection from a cross involving Robut 33-1, formed fewer nodules than Robut 33-1 with strain NC 92 in the 1981 season, and more in the 1982 season.

Table 31. Effect of mixing with other strains on the success of *Rhizobium* strain NC 92 in producing nodules on three groundnut cultivars in field trials, ICRISAT Center, rainy season 1981.

	Nodules/plant and percentage formed by NC 92							
	ICGS 15		J 11		Robut 33-1		Mean	
Inoculation treatment	Total (no.)	NC 92 (%)	Total (no.)	NC 92 (%)	Total (no.)	NC 92 (%)	Total (no.)	NC 92 (%)
No inoculum applied	510	2	350	4	420	1	430	2
Strain NC 92	510	25	390	30	460	30	460	28
Strain NC 92, 5a/70 and IC 6006	500	18	320	6	470	14	430	13
SE			±34	(±2.8)[a]			±19	±1.63
Mean	510	15	354	13.2	450	15.1		
SE			±19	(±2.0)[a]				

SE values do not apply to the 'no inoculum applied.'

a Values in parentheses represents SE for means of percentage of NC 92 nodules

Mixing other *Rhizobium* strains with NC 92 in the inoculum also affected the competitive ability of strain NC 92. Adding strain IC 6009 had little effect but the presence of strain 5a/70 reduced the competitive ability of strain NC 92, particularly in the 1981 rainy season.

Breeding for Increased N_2-fixation

We have earlier reported (ICRISAT Annual Report 1981, p. 185) that the germplasm line NC Ac 2821 had high nitrogenase activity. During

Table 32. Effect of mixing with other strains on the success of *Rhizobium* strain NC 92 in producing nodules on two groundnut cultivars in field trials, ICRISAT Center, rainy season 1982.

	Nodules/plant and percentage formed by NC 92					
	Robut 33-1		ICGS 15		Mean	
Inoculation treatment	Total (no.)	NC 92 (%)	Total (no.)	NC 92 (%)	Total (no.)	NC 92 (%)
No inoculum applied	210	1	200	1	210	1
Strain	200	25	210	36	210	30
Strains NC 92 and IC 6009	210	29	230	39	220	34
Strains NC 92 and 5a/70	220	20	220	20	220	20
SE[a]		±14(4.7)[b]		±10	±3.3	
Mean	210	19	210	24		
SE		±7.1 (4.7)[b]				

a. SE values do not apply to the 'no inoculum applied.'

b. Values in parentheses represent. SE for means of percentage of NC 92 nodules.

the 1981/82 postrainy season, in a diallel cross involving six parents selected for high or for low N_2-fixing activity, we observed that this line had good combining ability due to high additive genetic variance for traits associated with N_2-fixation nitrogenase activity, total nitrogen, leaf area, and top weight. This suggests that NC Ac 2821 may be useful in breeding for increased nitrogen fixation.

Drought

Research continued (in collaboration with the Agroclimatology, Soil Physics and Land and Water Management subprograms of the FSRP, ICRISAT Annual Report 1981), on how time and intensity of drought affect groundnuts, and on how manipulating groundnut populations alters the consequences of drought (in collaboration with the ODA-funded research program of the University of Nottingham's School of Environmental Physics).

Research was initiated on applied gypsum's effect on groundnuts' response to droughts of varied intensities during grain filling.

Screening Varieties for Drought Responses

We subjected 300 lines to 21 combinations of time, duration, and intensity of drought. The long-season lines did not germinate well, so we only analyzed data in detail from 200 early-maturing genotypes. Varied intensities of drought were created by using six irrigation treatments across the gradient of a line-source system developed by Hanks et al. in 1976 at three phases of growth. In another treatment applied water was varied from the onset of flowering to the end of crop growth. Timings and variations

In an experiment to screen groundnut varieties for drought responses, varied intensities of drought were created by using line-source irrigation. Lines with better growth under stress have been identified for further testing.

in applied water relative to crop age and environment are presented in Table 33.

The plot size being only two rows may have permitted competitive differences to influence differences in total dry matter (TDM) of genotypes. A genotype with greater root growth could have exploited water available outside the plot at the expense of its immediate neighbors. That possibility may have helped us identify for further investigation lines with better than average root growth.

Effects of time of stress. Long-term stress (T_1) caused the greatest variation in TDM, from 320 g/m^2 with no water applied to 960 g/m^2 with 39 cm applied between flowering and maturing.

Early stress (T_2) caused only slight variations in accumulated TDM (660 g/m^2 with no water applied to 725 g/m^2 with 10.5 cm applied). With later stress (T_3 and T_4), effects of withholding all irrigation reduced TDM more (555 g/m^2, and 480 g/m^2, respectively) compared with 735 and 720 g/m^2 from full irrigation (14.5 and 16.5 cm, respectively).

Regression equations for TDM averaged over all genotypes are provided in Figures 8 and 9 which compare responses of selected genotypes and the average response.

Total pod weights in general were influenced most by amount of irrigation under long-term stress (T_2), where all-genotype yield averages varied from 10 g/m^2 with no irrigation to 430 g/m^2 with no stress. Each centimeter of water applied increased yield 10.6 g/m^2.

Early short-term stress (T_2) influenced pod yields much more than TDM. Zero irrigation

Table 33. Cumulative water applied (cm) to different treatments and mean weather data during the stress period on groundnut lines, ICRISAT Center, postrainy season 1981/82.

	Applied water (cm)							
Treatments	T_1		T_2		T_3		T_4	
Period of stress (DAS)	50-129		50-84		74-102		102-129	
Replicate	R1	R2	R1	R2	R1	R2	R1	R2
Irrigation 1	37.5	41.1	10.6	10.3	14.8	14.1	15.8	17.8
2	35.0	38.0	9.6	9.2	13.5	12.9	14.9	16.8
3	29.5	30.5	8.0	8.6	10.8	10.6	12.5	13.4
4	20.1	19.0	5.5	4.9	6.8	7.1	8.9	8.1
5	9.5	7.9	2.6	2.3	2.8	3.3	4.3	3.4
6	2.3	1.7	0.7	0.6	0.7	0.9	0.9	0.9
Meteorological data								
Rainfall (mm)[1]	0.0		0.0		0.0		0.0	
Evaporation (mm)[1]	653		168		200		285	
Max. temp. (°C)	31.8		28.5		32.0		35.0	
Min. temp. (°C)	18.3		15.6		18.4		20.9	
Wind speed (kmph)	8.0		8.6		7.6		7.8	
Solar Radiation (MJ/M2/day)	20.2		18.4		19.4		22.7	
RH (% at 1417 hr)	76.2		87.6		72.6		68.5	
RH (%at 1417 hr)	32.6		38.5		32.0		27.4	

1. Rainfall and evaporation are totals, not means.
DAS = days after sowing.

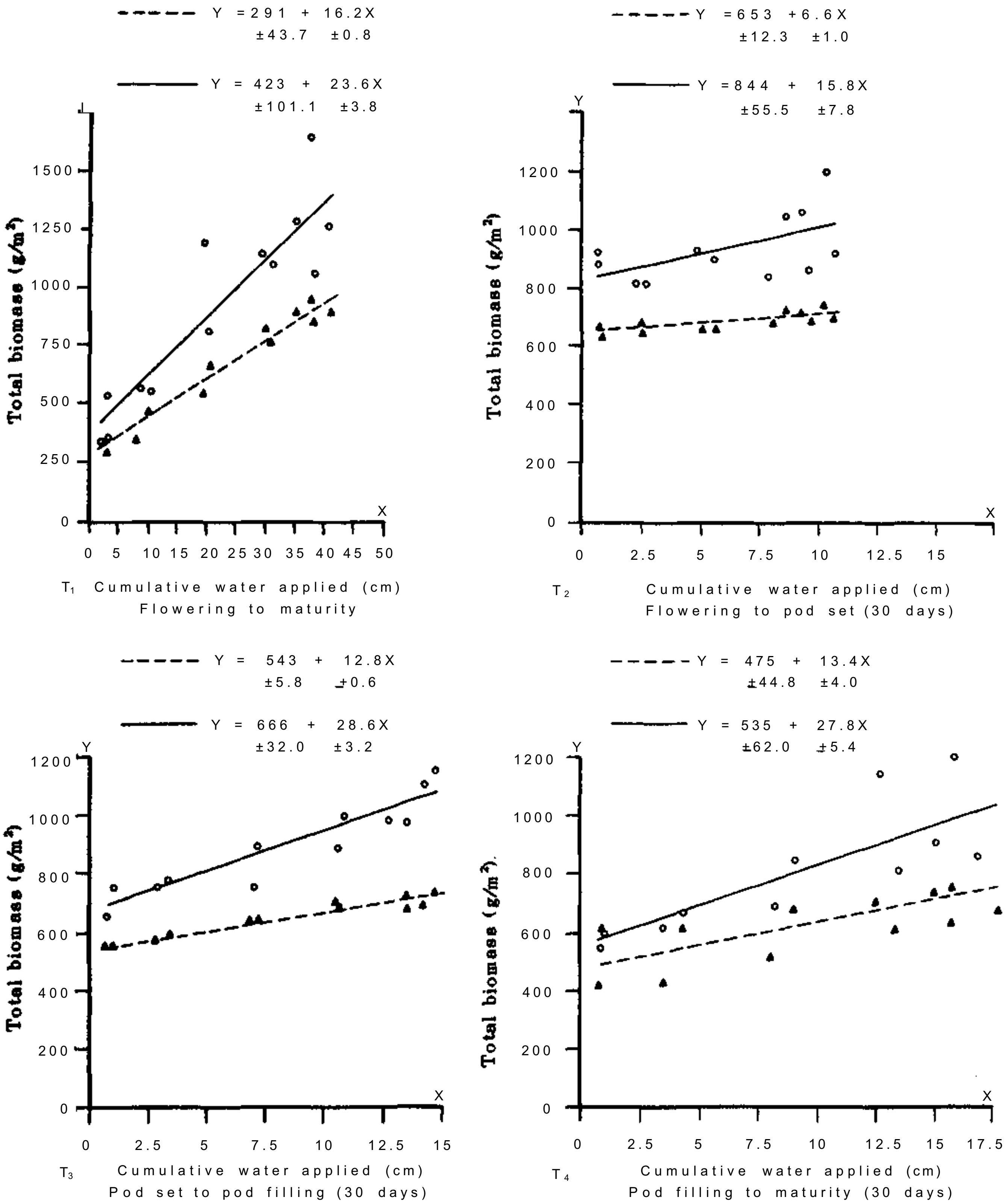


Figure 8. The response of total biomass to variations in applied water during each phase of growth for groundnut genotype ICG 1697 (o—) relative to the mean of 200 lines (▲—), ICRISAT Center, postrainy season 1981/82.

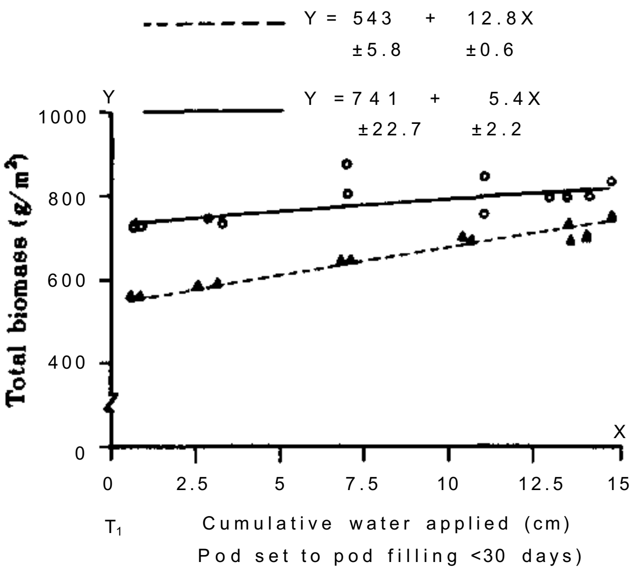


Figure 9. The response of total biomass to variations in applied water during each phase of growth for groundnut genotype ICG 4888 in Treatment 3, ICRISAT Center, postrainy season 1981/82.

gave an average yield of 230 g/m^2 and each centimeter of irrigation increased yield 9.4 g/m^2. On average treatment T_3 provided water during the most drought-sensitive growth phase. Withholding all water then decreased pod yield from 320 g/m^2 to 170 g/m^2, and each centimeter of irrigation increased yield 10.4 g/m^2.

Average pod yields were least influenced in T_4 but that treatment influenced TDM the most. Pod yield decreased from 310 g/m^2 to 210 g/m^2 when no water was applied during pod filling. Each centimeter of irrigation water increased yield only 6.8 g/m^2.

Selected genotypes. Examples of genotypes with responses statistically different *(P* < 0.05) from the mean are presented in Figures 8, 9, and 10.

In all stress treatments studied, genotype ICG 1697 (NC Ac 17090) produced more TDM than the average of the other 200 lines (Fig.8); its advantage was consistently greatest with better water relations. TDM of some genotypes, for example, ICG 4888 in treatment T_3 (Fig.9) was greater than average at the sparse end of water treatments but not greatly different when water supply was adequate.

Although ICG 1697 produced the most TDM under all treatments, its pod yield was better than average only under moderate irrigation in T_1. In treatment T_2, ICG 5305 was uniformly better than the average under all water treatments (Fig. 10).

T_3 produced two patterns of response: some varieties (e.g., ICG 4743) were uniformly better across all water levels, while others (e.g., ICG 1147) demonstrated little or no advantage at the wet end but little yield reduction from drought stress. In treatment T_4, variability was less than in other treatments, but some lines were better than average at all water levels, with the advantage greatest under dry conditions.

Interaction of Gypsum and Drought

Aborted and stunted groundnut seeds result from inadequate calcium uptake by the pod. Calcium deficiencies can develop in soils with low calcium-exchange capacity or when drought limits calcium's movement in the soil solution. Because drought interferes with calcium, we studied effects of gypsum applications on yields of different genotypes under varied intensities of drought stress.

In the postrainy season, we grew 24 early-maturing genotypes using two levels of gypsum in medium-deep Alfisol and varied drought stresses in six plots with line-source irrigation. After uniform irrigation up to 60 DAS, the crop received weekly line-source irrigations until it matured.

In some genotypes, ICG 4601 for example, gypsum was beneficial only with water deficits (Fig. 11), but gypsum increased yield of CGC 4063 (Fig. 12) at all irrigation rates; Manfredi x M. 13 showed no response to applied gypsum under the drought stresses we used (Fig. 13).

Even though ICRISAT soils are not considered deficient in calcium (exchangeable Ca ± 1100 ppm), we have shown that applying calcium increased yields of some genotypes, particularly under drought stress. More drastic effects seem likely when groundnuts are grown in calcium-deficient soils. Our results indicate that

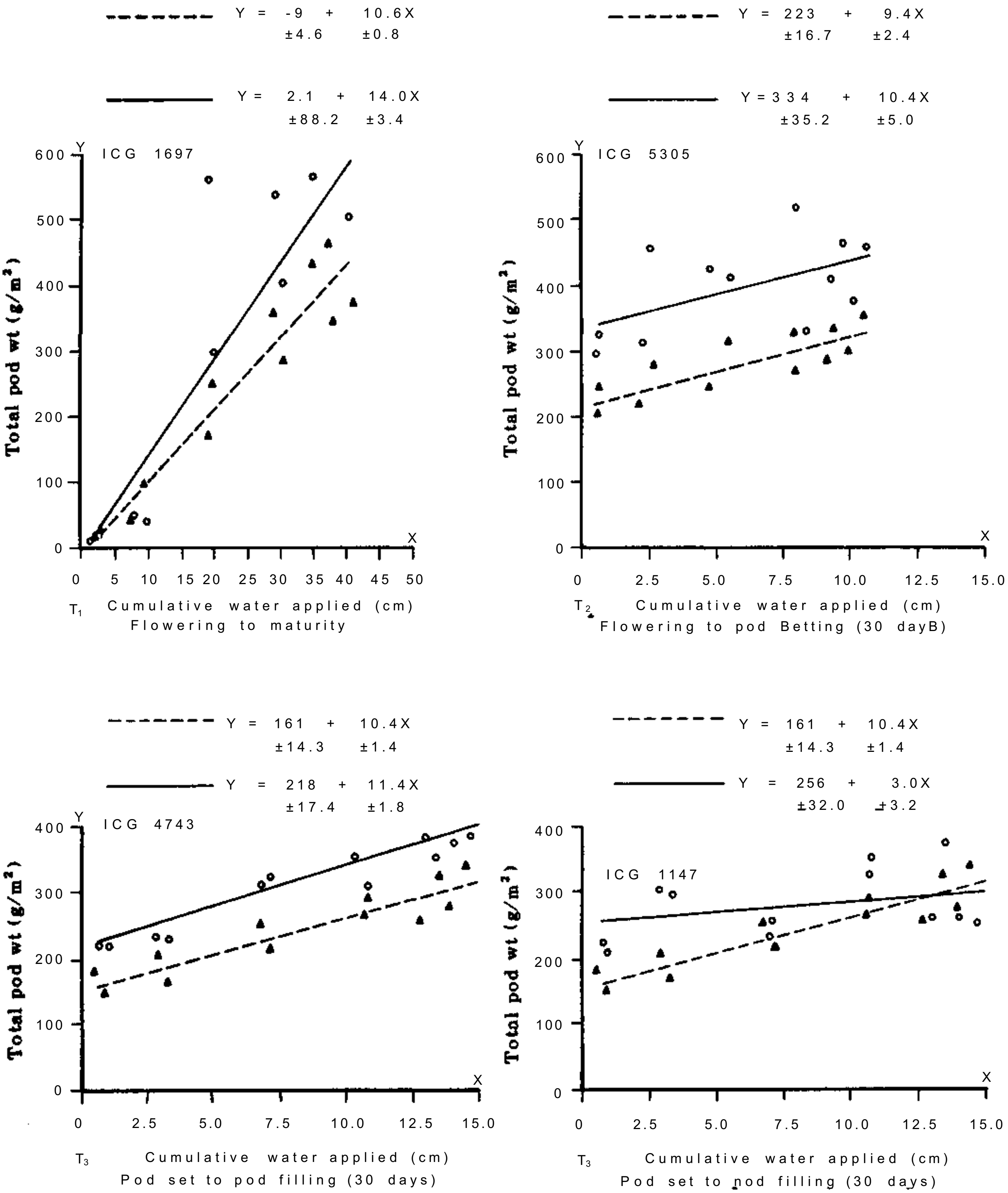


Figure 10. The response of pod yield to variations in applied water during different stages of development for selected groundnut genotypes (o—) relative to the mean response of 200 lines (▲----), ICRISAT Center, postrainy season 1981/82.

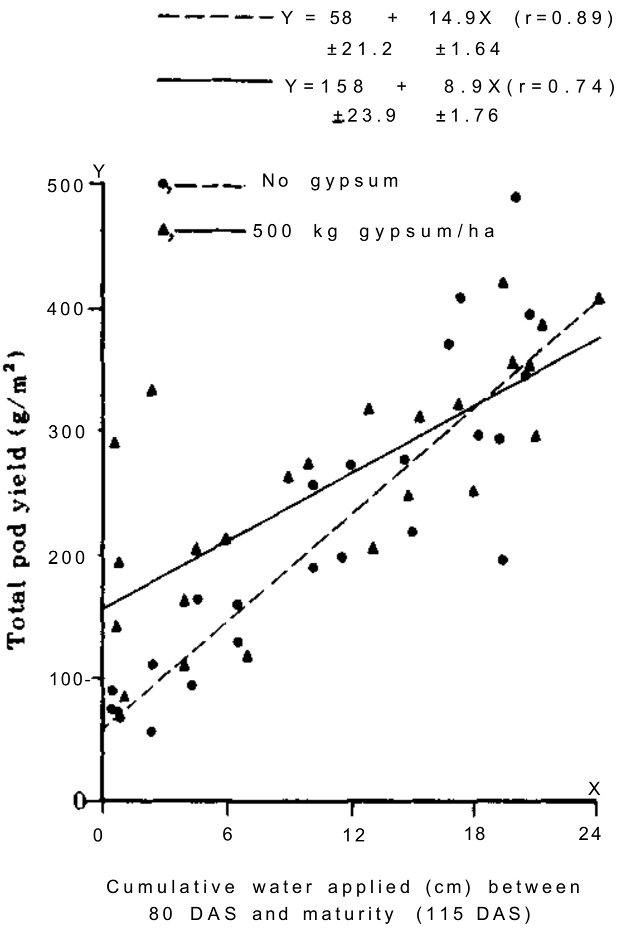


Figure 11. Effect of gypsum on the relationship between applied water and pod yield in ICG-4601 groundnuts, ICRISAT Center, postrainy season 1981/82.

gypsum could prove a major benefit to some cultivars under drought stress, but since gypsum may give no response under well-watered conditions further research and economic assessments are needed.

Effect of Time and Intensity of Drought

In collaboration with Agroclimatology, Soil Physics, and Land and Water Management subprograms of the FSRP, we repeated our study of the effects of timing and drought intensity on groundnuts. Yield responses were similar to those the preceding year (see Farming Systems section of this report for treatment details).

In the previous years' experiments, yield increases from early stress stemmed from changed growth distribution (ICRISAT Annual Report 1981), but in the 1982 experiment growth was stimulated by early stress with distribution remaining constant. The difference between years indicates that a study restricted to early stresses is necessary.

Plant Improvement

Breeding for High Yield and Quality

High-yielding breeding lines, particularly 1CGS lines, were crossed among themselves and with

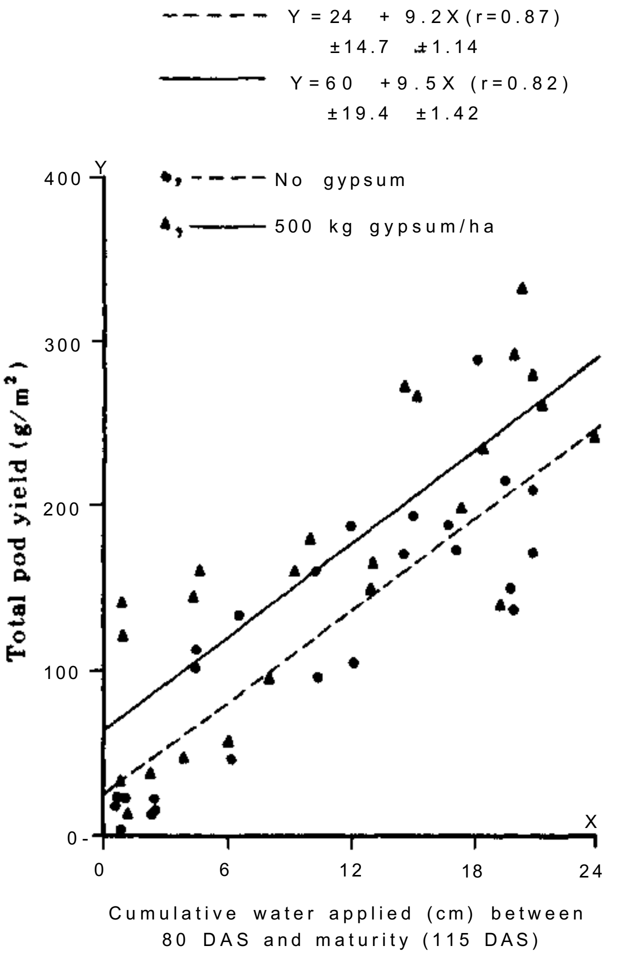


Figure 12. Effect of gypsum on the relationship between applied water and pod yield in CGC 4036 groundnuts, ICRISAT Center, postrainy season 1981/82.

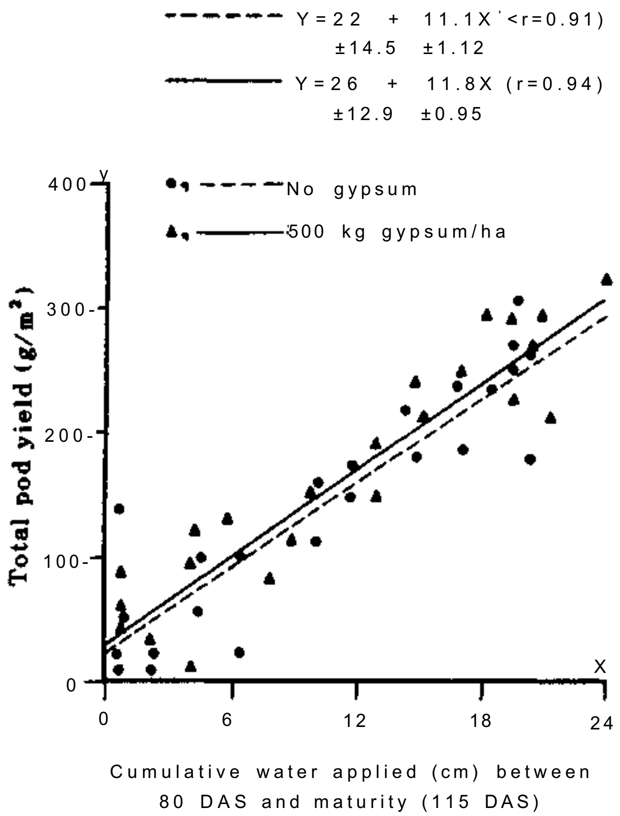


Figure 13. Effect of gypsum on the relationship between applied water and pod yield in CGC 4036 groundnuts, ICRISAT Center, postrainy season, 1981/82.

other germplasm lines to develop high-yielding lines suitable for a wide range of environments.

Based on high yield and other agronomic traits, 1435 high-yielding progeny bulks in F_3 to F_7 segregating generations were made from 778 crosses grown at ICRISAT Center during the 1981/82 postrainy season. Then we grew the selected bulks under both high- and low-input conditions during the 1982 rainy season. We made 1311 bulks from a high-input field and 648 from a low-input field and these selections are now being further evaluated.

Postrainy-season yield trials. During the 1981/82 postrainy season, 600 F_8 to F_{10} selections were evaluated in 10 trials, using the broadbed-and-furrow system in high-fertility Alfisol fields with protection against insect pests. Two Spanish bunch standard cultivars, J 11 and JL 24 and one Virginia bunch cultivar, Robut 33-1 were used as checks in all the trials. Only 6 trials—where the selections were superior to the check cultivars—are described here.

Yields of the five best yielding F_8 selections in the three trials are given in Table 34. Only two selections (NC Ac 2462 x TG 1) F_8B and (Florigiant x TG 16) F_8B significantly (P> 0.05) outyielded all three check cultivars.

Seventy-eight F_8 selections were compared with J 11, JL 24 and Robut 33-1 in a 9x9 triple-lattice trial. The pod yields of 10 superior selections are given in Table 35. Two selections, (JH 89 x Robut 33-1) F_9B_1 and (JH 89 x Robut 33-1) F_9B_2 produced more than 6000 kg/ha pod yield.

Sixty-one F_{10} selections and three check cultivars were evaluated in an 8x8 triple-lattice design. Seven selections produced pod yields of more than 6000 kg/ha (Table 36).

Based on consistent performance in previous seasons, 44 lines were assigned ICGS numbers. These, and two stable interspecific derivatives,

Table 35. Pod yields of the ten best F_9 groundnut selections, ICRISAT Center, postrainy season 1981/82.

Entry	Pod yield (kg/ha)
(JH 89 x Robut 33-1) F_9B_1	6220
(JH 89 x Robut 33-1) F_9B_2	6190
(JH 171 x Robut 33-1) F_9B_2	5980
(MGS 7 x Robut 33-1) F_9B_4	5950
(MGS 7 x Robut 33-1) F_9B_1	5940
(NC Ac 1107 x Robut 33-1) F_9B	5850
(JH 171 x Chico) F_9B	5840
(Robut 33-1 x NC Ac 316) F_9B_2	5830
(Robut 33-1 x NC Ac 316) F_9B_3	5790
(2-5 x Robut 33-1) F_9B_2	5790
Robut 33-1[a]	4940
JL 24[a]	5470
J 11[b]	5560
SE	±389
CV (%)	11

a. Local check cultivars.
b. National check cultivar.

Table 34. Pod yields of the five best F_8 groundnut selections, ICRISAT Center, postrainy season 1981/82.

Trial 1		Trial 2		Trial 3	
Entry	Pod yield (kg/ha)	Entry	Pod yield (kg/ha)	Entry	Pod yield (kg/ha)
(Florigiant x Spancross) F_8B_1	5950	(Starr x Robut 33-1) F_8B_2	6150	(NC Ac 2462 x TG 1) F_8B	6080
(NC Ac 2462 x TG 1) F_8B_2	5950	(Robut 33-1 x Comet) F_8B_1	5870	(Florigiant x TG 16) F_8B	6050
(Florigiant x Spancross) F_8B_2	5830	(Manfredi x Robut 33-1) F_8B_1	5800	(Ah 6279 x Robut 33-1) F_8B	5790
(NC Ac 2462 x Florigiant) F_8B_1	5800	(2-5 x Robut 33-1) F_8B_1	5750	(MH 1 x Robut 33-1) F_8B	5700
(NC Ac 2462 x TG 1) F_8B_1	5780	(Var 72-R x Robut 33-1) F_8B_1	5680	(Robut 33-1 x NC Ac 2821) F_8B	5670
J 11[a]	5370	J 11[a]	5380	J 11[a]	5360
JL 24[b]	4820	JL 24[b]	4780	JL 24[b]	5200
Robut 33-1[b]	5490	Robut 33-1[b]	5440	Robut 33-1[b]	5150
SE	±203		±272		±229
CV (%)	8		10		9

a. National check cultivar.
b. Local check cultivars.

and three check cultivars were grown in a 7x7 triple-lattice design. ICGS 30 gave the highest yield of 6600 kg/ha and 10 other lines yielded more than 6000 kg/ha (Table 37). All the selections were superior to JL 24.

Rainy-season yield trials. Several F_9, F_{10} and F_{11}, selections and ICGS lines were evaluated under high-input (60 kg P_2O_5/ha, irrigation and insecticides when required) and low-input conditions (20 kg P_2O_5/ha, rainfed and no insecticides). Eleven yield trials were conducted under high-input and nine under low-input conditions in the 1982 rainy season. Only four trials under each situation where the selections were superior to the standard check cultivars are described. Under low-input conditions the pod yields, in general, were low due to prolonged drought during pod development.

Yields of some of the F_9 Spanish bunch selections are given in Table 38. The four selections derived from Robut 33-1 x Tifspan and NC Ac

Table 36. Pod yields of the ten best F_{10} groundnut selections, ICRISAT Center, postrainy season 1981/82.

Entry	Pod yield (kg/ha)
(Ah 65 x Robut 33-1) $F_{10}B$	6200
(72-R x Comet) $F_{10}B$	6150
(Manfredi x M 13) $F_{10}B$	6130
(NC Ac 2741 x TMV 2) $F_{10}B_1$	6120
(X14-4-B-19-B x NC Ac 400) $F_{10}B$	6090
(X14-x-x-1-B x Goldin 1) $F_{10}B$	6050
(Spancross x J 11) $F_{10}B$	6050
(J 11 x TG 3) $F_{10}B_3$	5940
(NC Ac 2741 x TMV 2) $F_{10}B_2$	5940
(Tifspan x NC Ac 2944) $F_{10}B$	5940
Robut 33-1[a]	5500
JL 24[a]	4880
J 11[b]	5100
SE	±338
CV (%)	9

a. Local check cultivars.
b. National check cultivar.

Table 39. Pod yields (kg/ha) of F_{10} spanish and virginia bunch groundnut selections in the high- and low-input trials, ICRISAT Center, rainy season 1982.

Spanish bunch Trial			Virginia bunch Trial		
Entry	HI[a]	LI[b]	Entry	HI[a]	LI[b]
(MGS 9 x Robut 33-1) $F_{10}B$	2440 (1)[c]	1440 (2)	(MK 374 x Robut 33-1) $F_{10}B$	2400 (1)	1380 (4)
(JH 89 x Robut 33-1) $F_{10}B_1$	2040 (2)	1470 (1)	(M 13 x Robut 33-1) $F_{10}B$	2370 (2)	1230 (6)
(TMV 7 x Robut 33-1) $F_{10}B$	2040 (3)	1090 (10)	(Robut 33-1 x NC Ac 316) $F_{10}B$	2350 (3)	1420 (3)
(JH 89 x Robut 33-1) $F_{10}B_2$	1950 (5)	1240 (5)	(NC Ac 1107 x Robut 33-1) $F_{10}B$	2270 (4)	900 (18)
(72-R x Robut 33-1) $F_{10}B$	1820 (7)	1070 (13)	(MGS 7 x Robut 33-1) $F_{10}B$	2200 (5)	1500 (2)
(72-R x Chico) $F_{10}B$	1640 (13)	1360 (4)	(MGS 8 x Robut 33-1) $F_{10}B$	2170 (7)	1740 (1)
(JH 89 x Robut 33-1) $F_{10}B_5$	1410 (25)	1180 (6)	(Robut 33-1 x NC Ac 310) $F_{10}B$	2120 (9)	1270 (5)
Robut 33-1[d]	2020 (4)	1090 (11)	Robut 33-1[d]	1920 (11)	1220 (7)
JL 24[e]	1850 (6)	1380 (3)	JL 24[e]	2190 (6)	1170 (10)
J 11[e]	1600 (14)	840 (21)	J 11[e]	1380 (21)	1000 (13)
SE	±90	±142		±104	±89
CV (%)	11	27		11	16

a. See Table 38 fn a.
b. See Table 38 fn b.
c. Figures in parentheses are yield ranks.
d. Virginia check cultivar.
e. Spanish check cultivars.

Table 37. Pod yields of the best advanced lines, ICRISAT Center, postrainy season 1981/82.

Entry	Pod yield (kg/ha)
ICGS 30	6600
ICGS 21	6500
ICGS 26	6430
ICGS 16	6420
ICGS 25	6300
ICGS 23	6240
ICGS 37	6150
ICGS 35	6060
ICGS 44	6060
ICGS 9	6050
ICGS 12	6000
ICGS 32	5970
ICGS 22	5920
ICGS 27	5900
ICGS 14	5900
ICGS 33	5880
ICGS 36	5810
ICGS 20	5770
ICGS 4	5730
ICGS 38	5700
Robut 33-1 [a]	5450
JL 24 [a]	4760
J 11 [b]	5440
SE	±289
CV (%)	10

a. Local check cultivars.
b. National check cultivar.

2462 x M 13 performed well under both input levels.

Twenty six Spanish and 21 Virginia bunch F_{10} selections were evaluated in separate randomized-block design trials under both input levels, and yields of promising selections are presented in Table 39. In the Spanish bunch yield trial, selections (MGS 9 x Robut 33-1) $F_{10}B$, (JH 89 x Robut 33-1) $F_{10}B$, and (JH 89 x Robut 33-1) $F_{10}B_2$ did well under both input levels. Similarly, in the F_{10} Virginia bunch trial, (MK 374 x Robut 33-1) $F_{10}B$, (M 13 x Robut 33-1) $F_{10}B$, (Robut 33-1 x NC Ac 316) $F_{10}B$, and (MGS 7 x Robut 33-1) $F_{10}B$ performed well under both input levels.

During the season, 17 more selections were assigned 1CGS numbers. Of these, fifty-three ICGS lines and three check cultivars were evaluated for their yield potential under both the input levels. Table 40 shows pod yield of the 15 ICGS lines, all of which except ICGS 37 in the low-input trial significantly outyielded J 11 ($P < 0.05$).

Yield Physiology

A range of established Indian cultivars and some of the genotypes which have been extensively used in ICRISAT's crossing program were studied by growth analysis under nonlimiting conditions in both the rainy and postrainy seasons (Table 41). To allow comparison of the crop growth rate (CGR) and pod growth rate (PGR), the pod dry matter (PDM) and the total dry matter (TDM) were adjusted for the greater energy content of the pods using a factor of 1.65.

Table 38. Pod yields of F_9 Spanish bunch groundnut selections in the high- and low-input trials ICRISAT Center, rainy season 1982.

Entry	Pod yield (kg/ha)	
	HI[a]	LI[b]
Robut 33-1 x Tifspan) F_9B_1	270 (1)[c]	1000 (2)
(Robut 33-1 x Tifspan) F_9B_2	2260 (2)	1080 (1)
(NC Ac 2462 x M 13) F_9B_1	2180 (3)	850 (3)
(NC Ac 2462 x M 13) F_9B_2	2130 (4)	850 (4)
(MGS 7 x Robut 33-1) F,B,	2020 (6)	720 (13)
(Var 72-R x Robut 33-1) F_9B	1790 (13)	840 (5)
JL 24[d]	2030 (5)	770(11)
Robut 33-1 [d]	1980 (7)	790 (9)
J 11[e]	1340 (27)	620 (19)
SE	±85	±70
CV (%)	±10	20

a. HI = High input: 60 kg P_2O_5/ ha, supplementary irrigation, protection from insect pests.
b. LI = Low input 20 kg P_2O_5/ha, no irrigation, no protection from insect pests.
c. Figures in parentheses are yield ranks.
d. Local check cultivars.
e. National check cultivar.

Table 40. Pod yields of the ten best ICGS lines in the high- and low-input trials, ICRISAT Center, rainy season 1982.

ICGS no./cultivar	Pod yield (kg/ha) HI[a]	Pod yield (kg/ha) LI[b]
50	2820 (1)[c]	1820 (1)
47	2510 (2)	1390 (9)
36	2490 (3)	1380 (11)
43	2430 (4)	1600 (3)
46	2370 (5)	1320 (14)
27	2330 (6)	1130 (24)
37	2320 (7)	1000 (29)
44	2320 (8)	1800 (2)
38	2310 (9)	1090 (26)
30	2300 (10)	1160 (21)
33	2290 (11)	1500 (7)
1	2260 (13)	1540 (6)
11	2250 (14)	1590 (4)
5	2220 (17)	1390 (10)
53	2050 (29)	1450 (8)
15	2020 (32)	1570 (5)
Robut 33-1[d]	2080 (26)	960 (38)
JL 24[d]	2010 (33)	970 (32)
J 11[e]	1450 (54)	640 (54)
SE	±104	±143
CV (%)	10	26

a. See Table 38 fn a.
b. See Table 38 fn b.
c. Figures in parentheses are yield ranks.
d. Local check cultivars.
e. National check cultivar.

The CGR and PGR of these eight lines, and the proportion of growth partitioned into reproductive growth, provided an indication of the extent of yield improvement which is still possible by breeding for increased partition of the total assimilates into pod yield.

The new Indian cultivar Robut 33-1 and a natural hybrid from it had a high partitioning factor (PF) (about 95%), suggesting that only small improvements in yield potential can be expected from continued selection for improved partitioning. The very-early-maturing genotype Chico had complete partitioning into reproductive components (100% PF) but also had the lowest CGR.

There were some season x genotype interactions detected for both CGR and PF. Cultivar M 13 had an above-average CGR, and a PF of 85% during the postrainy season, but the lowest CGR and a greatly decreased PF (59%) in the rainy season. TMV 2 had in each season a low PF (68% in the postrainy season and 83% in the rainy season), but compensated for this by having a CGR consistently above average ($P < 0.05$) in the high temperature and radiation conditions of the postrainy season. The seasonal variations in the PF in both M 13 and TMV 2 are of considerable interest; we are investigating this further.

Earliness and Dormancy

Screening. In our continuing efforts to identify early-maturing dormant lines in breeding populations derived from crosses of early, nondormant with dormant, long-season types, we screened 335 bulk seed samples from plants with the morphological attributes of the early-maturing parent.

Some of the bulk seed selections from these crosses were found to exhibit varied proportions of dormant seeds. Single plant selections were made to identify those with all seed dormant for at least 15 days after rehydration or sowing. Continued laboratory and field testing of these lines and the lines reported in the 1981 Annual Report have shown our screening methods to be effective for identifying dormant seeds from breeding lines.

Eight lines containing seed with dormancy lasting at least 15 days were isolated and purified by this process (Table 42). These are now being bulked for use in other evaluation procedures and crossing programs.

In crosses of Robut 33-1 with Makulu Red (F_6), NC Ac 2821 (F_8), and NC Ac 2698 (F_{10}), although both the parents belong to subsp. *hypogaea,* plants with sequential branching and erect habit (like subsp. *fastigiata* var *vulgaris)*

Table 41. Crop growth rates, pod growth rates, and growth distribution into reproductive structures in a range of groundnut genotypes, ICRISAT Center, 1981/82.

Cultivar/ genotype	Crop growth rate[1] (g/m² per day)	SE	Pod growth rate[1] (g/m² per day)	SE	Partitioning factor
			1981 Rainy season		
Robut 33-1	17.4	±0.38	10.1	±0.69	95
Robut NH	19.1	±1.36	10.8	±1.18	93
TMV 2	18.4	±0.53	9.2	±0.24	83
Chico	16.3	±0.75	9.2	±0.92	93
M 13	15.3	±0.80	5.5	±0.14	59
J 11	17.4	±0.38	9.3	±0.29	88
			1981/82 Postrainy season		
Robut 33-1	20.4	±0.40	11.8	±0.33	95
Robut NH	22.6	±1.87	12.8	±1.09	93
TMV 2	25.0	±0.33	10.4	±0.20	68
Chico	15.2	±0.69	9.2	±0.43	100
M 13	21.1	±0.44	10.9	±0.60	85
MH 2	19.9	±0.91	7.3	±0.10	85

1. Adjusted for the energy content of the pods to dry-matter equivalent.

were selected from the segregating populations and dormant lines identified from them.

Breeding for earliness. Two new sources of earliness, TG 1E and TG 2E, and a number of early-maturing breeding lines with large seed size were crossed with high-yielding varieties and ICGS lines. Many single-plant selections and progeny bulks based on early flowering and maturity were made from the F_3 to F_{10} segregating generations, and are being further evaluated for their earliness and yield potential in replicated trials.

Table 42. Eight early maturity groundnut lines with at least 15 days dormancy, ICRISAT Center, rainy season 1982.

1.	NC Ac 475 x M 13 (F_8)
2.	M 13 x Gangapuri[a] (F_6)
3.	Ah 2105 x Chico[a] (F_9)
4.	2-5[a] x Robut 33-1 (F_8)
5.	SM 5[a] x NC Ac 17500 (F_4)
6.	TMV 10 x Chico[a] (F_8)
7.	MH 2[a] x 28-206 (F_8)
8.	NC Ac 1107 x X14-4-B-19-B[a] (F_8)

a. Early maturing nondormant parents.

Yield trials. We evaluated 13 early-maturing advanced selections in the 1981/82 postrainy season and 20 in the 1982 rainy season. The performance of the five best selections is presented in Table 43. Entries (JH 89 x Chico) F_9B and (72-R x Chico) F_9B were among the top five selections in both the rainy and postrainy seasons.

Photoperiod Effects

It is known that in groundnuts the reproductive processes can be modified by photoperiod effects. This phenomenon has considerable implications for the adaptability of selections made by breeders at ICRISAT and for the value

Table 43. Performance of five best early-maturing groundnut selections, ICRISAT Center, 1981-82.

1981/82 postrainy season				1982 rainy season			
Entry	Days to flowering	Days to maturity	Pod yield (kg/ha)	Entry	Days to flowering	Days to maturity	Pod yield (kg/ha)
(TMV 7 x Chico) F_9B_1	34	116	5800	(Ah 330 x 91176) F_5B_1	18	93	2440
(JH 89 x Chico) F_8B	35	120	5590	(NC Ac 2748 x Chico) $F_{10}B_1$	22	101	2120
(72-R x Chico) F_8B	35	120	5560	(72-R x Chico) F9B	23	104	2130
(Manfredi x Chico) F_7B	38	137	5470	(JH 89 x Chico) F_9B	23	92	2000
(Argentine x Chico) F_9B	34	120	5030	(Chico x NC 344) F_5	19	91	1890
Chico [a]	32	108	3640	Chico [a]	20	91	1780
J 11 [b]	37	127	5510	J 11 [b]	27	104	1920
JL 24 [c]	39	137	4730	JL 24 [c]	27	108	2190
SE	±0.5	±2.1	±171		±0.6	±1.4	±116
CV (%)	3	4	8		5	3	13

a. Early maturity parent. b. National check cultivar. c. Local check cultivar.

of germplasm distributed to regions with differing photoperiod regimes.

Six genotypes were grown under both long (16 hr) and normal (11 to 12 hr) daylength conditions. For long days Tungsten lamps were used at a density which provided extra light of at least 30 lux. The effect of photoperiod on the harvest index (energy adjusted) for these lines is presented in Table 44.

Some lines were greatly influenced by the photoperiod (with their harvest index changing by 12%), while for others the photoperiod change had little or no impact.

Table 44. Harvest indices (%) of some groundnut genotypes grown under normal-day and long-day photoperiods, ICRISAT Center, postrainy season, 1981/82.

	Photoperiod	
Genotype	Normal day	16-hr day
TMV 2	58.8	54.6
NC Ac 17090	57.9	49.2
Robut 33-1	61.7	61.4
S 7-2-13	47.0	41.6
M 13	45.2	42.7
PI 259747	57.3	44.6
SE	±1.79	

Inheritance of Albinism

Thirty-nine F_2 populations derived from infra-subspecific and intra-specific crosses were studied for green vs albino seedlings a week after emergence. F_2 data for various digenic and trigenic ratios were analyzed. Individual chi-square, (except in ICGS 7 x NC Ac 2232), pooled chi-square and total chi-square were all nonsignificant for 63 green: 1 albino F_2 ratios, indicating that albinism is controlled by triple recessive factors.

Utilization of Wild Species

We have concentrated on incorporating genes from wild species into *A. hypogaea,* to advance our hybrids one or two generations, while selecting for desirable characters and analyzing cytologically as necessary. We also produced hybrids with wild species newly introduced to ICRISAT. Studies on barriers to hybridization continued with significant progress in producing pegs and pods from crosses previously considered incompatible, and in culturing ovules and embryos from some of the pegs and pods.

Interspecific Breeding and Screening for Disease Resistance

We continued crosses between wild species, between *A. hypogaea* and wild species, and between *A. hypogaea* and wild species derivatives. Three new diploid accessions and two new tetraploid accessions, originating from collections in South America during 1976 and 1977, were crossed with *A. hypogaea* (Table 45). Two new diploid accessions (collection nos. 30007 and 30080) were treated with colchicine to produce autotetraploids.

Our major hybridization effort was backcrossing hybrids to *A. hypogaea.* Sixteen amphiploids have been backcrossed; five have been advanced to the third backcross generation, and 13 fertile derivatives with regular meiosis selected (Table 46). Meiotic stability was obtained in BC_2 in some cases. Five autotetraploids were also crossed with *A. hypogaea,* and six fertile stable derivatives obtained from four combinations (Table 47). Crossability is low in early generations but usually increases with successive backcrosses.

A wide range of hexaploids, grown in the field between infector rows, was scored for reactions to rust and leaf spot diseases. Selected hexaploids were crossed with *A. hypogaea* to reduce the chromosome number and eliminate undesirable wild species characters.

We selected 184 single plants from 412 progeny rows. Plants were selected from 14 progeny rows from crosses involving *A. cardenasii;* from 13 rows from crosses involving *A. chacoense;* and from 28 rows from crosses involving *A. stenosperma* (HLK 410). Pods from nonselected lines were put in cold storage for later screening for resistance to other pests and diseases.

Hexaploids selected in the 1981 rainy season were backcrossed to a range of *A. hypogaea* cultivars (Table 48). The chromosome number was eventually reduced from 2n = 60 to 2n = 40, so meiotically stable and fertile derivatives were not obtained in early generations, but a total of 20 lines are fertile and stable. Hexaploids and backcrosses both form gametes with a wide range of chromosome numbers. Thus 51- to 60-chromosome plants can occur even in BC_3.

Triploids, which were previously considered sterile, produced pods. Their progeny ranged in

Table 45. Crossability between *A. hypogaea* and some new accessions of wild species, ICRISAT Center, rainy season 1982.

Cross	Pollinations (no.)	Pegs (no.)	Pods (no.)	Pods/ pollinations (%)
A. hypogaea (2)[a] x *Arachis* sp 30007 (2x)	809	182	76	9
A. hypogaea (3) x *Arachis* sp 30060 (2x)	940	115	43	5
A. hypogaea (3) x *Arachis* sp 30069 (2x)	188	45	29	15
A. hypogaea (3) x *Arachis* sp 30062 (4x)	224	60	35	16
A. hypogaea x *Arachis* sp 30063(4x)	691	138	103	15

a. Number of cultivars used.

Table 46. Pod production in backcrosses of amphiploids to *A. hypogaea*, ICRISAT Center, 1981-82.

A. hypogaea x amphiploid	BC1				BC2				BC3				Fertile stable derivatives obtained (no.)
	Pollinations (no.)	Pegs (no.)	Pods (no.)	Pods/pollinations (%)	Pollinations (no.)	Pegs (no.)	Pods (no.)	Pods/pollinations (%)	Pollinations (no.)	Pegs (no.)	Pods (no.)	Pods/pollinations (%)	
A. villosa x *A. batizocoi*	1024	248	89	9	159	38	11	7	31	4	1	3	1
A. correntina x *A. batizocoi*	215	27	10	5	850	135	41	5	241	27	14	6	1
A. batizocoi x *A. correntina*	362	31	20	6	53	17	5	9					
A. batizocoi x *A. chacoense*	217	69	36	17	76	18	17	22					
A. batizocoi x *A. duranensis*	726	138	41	6	247	56	32	13	116	18	4	3	1
A. duranensis x *Arachis* sp 10038	460	88	26	6	71	22	5	7					
Arachis sp 10038 x *Arachis* sp HLK-410	232	39	5	2	386	167	26	7	174	37	22	13	2
Arachis sp HLK-410 x *Arachis* sp 10038	78	8	6	8									
Arachis sp HLK-410 x *A. chacoense*	310	80	44	14	131	29	17	13					1
A. duranensis x *Arachis* sp HLK-410	160	23	14	9									
A. villosa x *Arachis* sp HLK-410	686	105	73	11	236	79	51	22					1
A. villosa x *A. duranensis*	196	49	19	10									
A. correntina x *A. chacoense*	99	24	22	22	265	57	41	15					1
A. duranensis x *A. chacoense*	283	69	51	18	118	45	32	27	48	12	10	21	1
A. correntina x *A. villosa*	893	157	62	7	54	33	1	2					1
A. correntina x (*A.chacoense* x *A. cardenasii*)	404	72	33	8	697	214	114	16					2
Total	6345	1227	551	9	3343	910	393	12	610	98	62	10	13

Table 47. Pod production in backcrosses of autotetraploids to *A. hypogaea*, ICRISAT Center, 1981-82.

Autotetraploid	BC$_1$ Pollinations (no.)	BC$_1$ Pegs (no.)	BC$_1$ Pods (no.)	BC$_1$ Pods/pollinations (%)	BC$_2$ Pollinations (na)	BC$_2$ Pegs (no.)	BC$_2$ Pods (no.)	BC$_2$ Pods/pollinations (%)	BC$_3$ Pollinations (no.)	BC$_3$ Pegs (no.)	BC$_3$ Pods (no.)	BC$_3$ Pods/pollinations (%)	Fertile stable derivatives obtained (no.)
A. batizocoi	1012	203	59	6	1441	270	103	7	279	51	36	13	3
A. villosa	368	20	20	5	31	4	2	6					1
A. correntina	50	1	1	2	10	4	2	20					1
Arachis sp HLK-410	301	15	9	3	50	8	7	14	51	4	2	4	
Arachis sp 10038	75	13	8	11									1
Total	1806	252	97	5	1532	286	114	8	330	55	38	12	6

Table 48. Pod production in backcross of *A. hypogaea* (4x) x Wild species (2x) hexaploid to *A. hypogaea*, ICRISAT Center, 1981-82.

Hexaploids	BC$_1$ Pollinations (no.)	BC$_1$ Pegs (no.)	BC$_1$ Pods (no.)	BC$_1$ Pods/pollinations (%)	BC$_2$ Pollinations (no.)	BC$_2$ Pegs (no.)	BC$_2$ Pods (no.)	BC$_2$ Pods/pollinations (%)	BC$_3$ Pollinations (no.)	BC$_3$ Pegs (no.)	BC$_3$ Pods (no.)	BC$_3$ Pods/pollinations (%)	BC$_4$ Pollinations (no.)	BC$_4$ Pegs (no.)	BC$_4$ Pods (no.)	BC$_4$ Pods/pollinations (%)	BC$_5$ Pollinations (no.)	BC$_5$ Pegs (no.)	BC$_5$ Pods (no.)	BC$_5$ Pods/pollinations (%)	Fertile stable derivatives obtained (no.)
A. hypogaea x *A. cardenasii*	1277	143	109	9	2538	749	459	18	577	147	69	12	35	13	9	26					9
A. hypogaea x *A. chacoense*	302	24	19	6	321	77	33	10	303	58	51	17	177	21	13	7	94	25	15	16	9
A. hypogaea x *A.* sp HLK 410	254	51	36	14	148	24	23	16	721	125	57	8	28	2	1	4					2
A. hypogaea x *A. correntina*	56	20	14	25	252	16	12	5													
A. hypogaea x *A. villosa*	224	48	16	7																	
A. hypogaea x *A. batizocoi*	179	21	17	10																	
Total	2292	307	211	9	3259	866	527	16	1601	330	177	11	240	36	23	10	94	25	15	16	20

Triploid interspecific hybrids are used to transfer the desirable traits of wild species into agronomically acceptable groundnut cultivars.

chromosome number from 2n = 20 (diploid) to 2n = 60 (hexaploid) (Fig. 14), which provides a way to obtain hexaploids and tetraploids without colchicine treatment and backcrossing. We investigated the cytological basis for triploid fertility by observing cells at meiosis, where chromosome distribution was unequal and spindle abnormalities were common (Table 49).

Table 49. Chromosome distribution at stages AI and A II, and pollen stainability in triploids, ICRISAT Center 1980-81.

% of cells with	Stage A I	Stage A II	Pollen stainability (%)
Equal distribution (15-15)[a]	34	70	-
Unequal distribution	19	20	3.5 [b]
Laggards	38	2	-
Bridges	7	0	-
Spindle breakdown or fusion	2	8	10.3 [c]

a. Generally produce inviable gametes.
b. Pollen of variable size.
c. Mostly large stainable pollen from unreduced gametes.

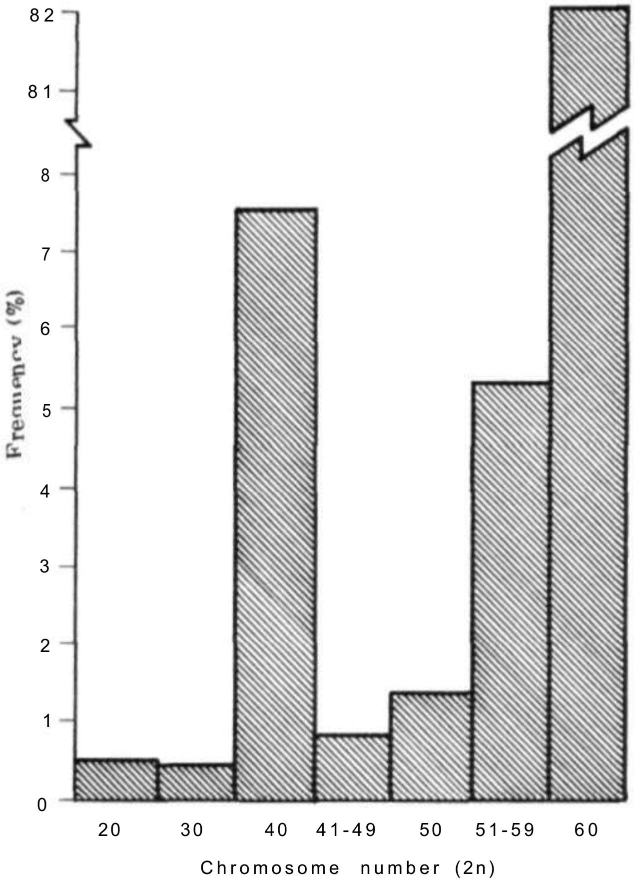


Figure 14. Frequency of groundnut plants with indicated chromosome numbers among 225 plants derived by selfing triploids (three plants showed variation between cells in chromosome numbers of 30 to 60).

The hybrids produced were exposed to diseases in the field at ICRISAT Center, and resistant plants selected with emphasis on resistance to late leaf spot (*Cercosporidium personatum)* (Table 50). Detached leaves of a few lines were placed in sterile sand in trays in a growth chamber and sprayed with spore suspensions of individual pathogens to confirm observed resistances (Fig. 15).

Selections from wild species derivatives obtained from North Carolina State University were multiplied in the 1981/82 postrainy season and screened in the field between infector rows in the 1982 rainy season.

Fifty-two selections, 2 breeding lines, and 5 entries each of 2 local checks were combined in a triple-lattice trial, and 1500 lines were grown in unreplicated plots at ICRISAT Center.

Selected lines were grown in a replicated field trial at Bhavanisagar to assess leaf spot resistance in the absence of rust disease.

The entries in both these trials were assessed for several characters, with emphasis on rust resistance, leaf spot resistance, and yield. Records were taken also of pod rot severity, haulm weight at harvest, pod cleanliness, oil content, and seed dormancy.

High-yielding lines were identified in derivatives incorporating *A. cardenasii.* Some with good haulm yields and satisfactory oil content resisted late leaf spot and rust (Table 51). Pod and seed characters were acceptable. Pods of some lines had little soil adhering at harvest.

From more than 800 advanced stable progeny rows grown to assess disease reaction, 51 progenies were highly resistant to both rust and leaf spot and 4 highly resistant to rust and resistant to leaf spot. Additionally 98 lines resisted one pathogen only.

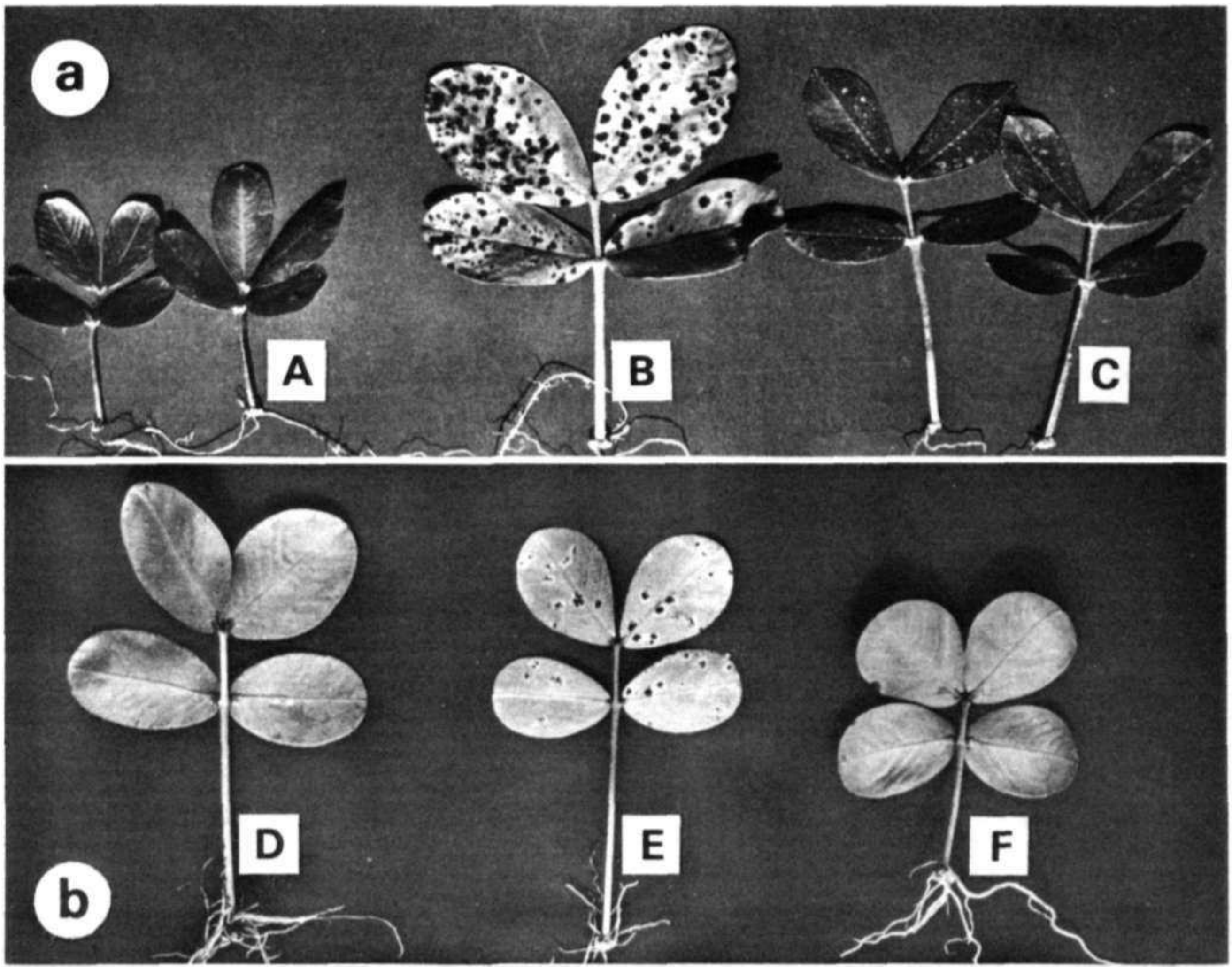


Figure 15. To confirm observed resistances to diseases—especially rust and late leaf spot—of plants selected, we placed detached leaves of a few lines in sterile sand and sprayed them with spores. At top are detached leaves of (A) (*A. hypogaea x A. cardenasii) x A. hypogaea,* (B) *A. hypogaea* TMV 2, and (C) *(A. hypogaea* x 1. sp. HLK k 410) x *A. hypogaea* BC_3, all sprayed with a spore suspension of *Cercosporidiumpersonatum;* at bottom, detached deaves of *(D)A. hypogaea x* (amphiploid *A. hatizocoi x A. duranensis), (E)A. hypogaea* TMV 2, and *(F)A. hypogaea x (A. hypogaea* x autotetraploid *A. hatizocoi),* all sprayed with a spore suspension of *Puccinia arachidis.*

Table 50. *Cercosporidum personatum* resistant plants selected from F_2 populations of stable tetraploid derivatives of *A. hypogaea* x wild species, ICRISAT Center, rainy season 1982.

Genotype	Generation	No. of plants selected
From selfed triploids:		
(HGKst x H11) x H14	BC_2F_2	9
(HGKst x H11l) x H15	BC_2F_2	2
(HGKst x H11) x H17	BC_2F2	3
From hexaploids:		
HJK 53/1 x H20	BC_1F_2	19
HJK 53/1 x H19		4
HJK 54/1 x H19	ft	20
HJK 54/1 x H20		13
HJK 57/7 x H14	ft	1
HJK 57/7 x H19		20
H19 x HJK 53/1		1
HIJ x ((3HIL13b/1hba x H4(1)) x H11)	BC_3F_2	1
H21 x ((HIL13b/ 1hba x H4(1)) x H11)	BC F_2	3
H24 x ((HIL13b/1hba x 4(1)) x H11)	BC_3F_2	7
H25 x ((HIL13b/1hba x H4(1)) x H11)		5
H12 x (HSaC 3/10BC_3 x HS(2))	ft	7
H23 x (12 x (HSaC 3/10 BC_3 x HS(2))	BC_4F_2	5
(HSaC 3/10 BC_2 x HS(1)) x HL (1))H11	BC_4F_2	1
From autotetraploids:		
H12 x (H11 x *A. batizocoi(4x))*	BC_1F_2	3
Total		124

HJK, HGK = *A. hypogaea* x *A. cardenasii* hybrids.
HSaC = *A. hypogaea* x *A. chacoense* hybrids.
HIL = *A. hypogaea* x *Arachis* sp HLK 410 hybrids.
HS, HL, H11 to H25 = *A. hypogaea* cultivars.

Barriers to Hybridization

Our earlier attempts to produce intersectional hybrids (ICRISAT Annual Reports 1979/80, 1981) revealed that gibberellic acid could be effectively used to produce pegs, pods, and ovules after hybridization between *A. hypogaea* and species in section *Rhizomatosae,* species previously considered cross-incompatible. We now have overcome incompatibility in a range of intersectional crosses by treating the bases of incompatibly pollinated flowers with gibberellic acid, and we have used a wide range of cultivars as female parents, particularly in the important crosses of *A. hypogaea* with the tetraploid species of the section *Rhizomatosae* (Table 52). The number of pegs produced after one treatment with gibberellic acid was good (42-79%), but the number of pods produced was not satisfactory (0-46%).

Our previous results indicated that pegs induced by gibberellin may be stimulated by other plant growth hormones, e.g. indole acetic acid (IAA) or kinetin, to produce pods and seeds. We incorporated IAA or kinetin at various concentrations into lanolin to apply to gynophore bases at different times after pollination. We concentrated on the cross *A. hypogaea* cv Robut 33-1 x *Arachis* sp. PI 276233, but we also used other cultivars as female parents.

IAA treatments. IAA treatments increased the pod numbers in crosses of both *A. hypogaea* cvs Robut 33-1 (Table 53) and M 13 with Arachis sp. PI 276233.

In Robut 33-1 some auxin treatments produced larger ovules with larger embryos than those in pods from gibberellin treatments only (Table 53).*A. hypogaea* cvs M 13 and Robut 33-1 reacted similarly in pod production. In cv MK 374 (Table 54) IAA was applied only on day 15 after pollination, but there was no marked improvement in pod production, ovule lengths, or embryo lengths.

Kinetin treatments. Some kinetin treatments increased production of pods in cv Robut 33-1 x*Arachis* sp. PI 276233 (Table 55), and cv M 13 x *Arachis* sp. PI 276233 which is similar to the effect of IAA. Kinetin treatments produced longer ovules and longer embryos in the cross with Robut 33-1 as the female parent, but not in the cross with M 13.

Table 51. Disease reaction (1-9 scale) and yield (kg/ha) of selected wild species derivatives, (8 x 8 triple lattice, plot size 16 m^2) ICRISAT Center and Bhavanisagar, rainy season 1982.

Entry No.	Rust resistance	Leaf spot[1] resistance	Pod yield	Kernel yield (est)	Oil content (%)	Oil yield (est)	Haulm yield
13	2.3	2.3	3150	1960	42	820	4570
30	2.7	2.3	2640	1700	44	760	6540
46	6.7	2.3	2540	1740	44	770	4490
6	2.7	2.3	2150	1360	43	580	3700
11	2.7	2.0	2520	1750	44	770	5620
23	3.0	3.0	2140	1410	44	620	5060
39	9.0	2.3	2130	1370	45	610	3270
SE	±0.42	±0.55	±134	±87	±0.7	±39	±350
Check							
Robut 33-1	9.0	6.3	1830	1320	41	510	1560
TMV 2	9.0	9.0	1240	850	41	350	1630
SE	±0.0	±0.24	±80	±60	±0.3	±24	±53
Site mean[2]	4.2	5.5	1950	1280	43	550	4050
CV (%)	17	17	12	12	3	12	15

1. Results from trial at Bhavanisagar.
2. Mean of 64 entries (ICRISAT Center) 36 entries (Bhavanisagar).

In both IAA and kinetin treatments, pegs treated on day 20 after pollination gave better results than those treated any other day. Cultivars responded differently to hormone treatments.

Culture of Ovules and Embryos

***A. hypogaea* x *Arachis* sp. PI 276233.** Most pods from the different crosses (Tables 52 to 55) contained small seeds that had to be cultured in toto, though some were large enough to dissect out and culture the embryos. Of 904 ovules cultured from crosses of five *A. hypogaea* cultivars, 248 (27%) were successfully established in culture. Of 291 embryos, 59(20%) were established, and some have been transferred to soil.

Other intersectional crosses. Ovules or embryos have been cultured from crosses between sections *Arachis* and *Triseminale, Extranervosae,* and *Erectoides,* and between *Extranervosae* and *Erectoides.*

Table 53. Effect of IAA in lanolin on pod-set and ovule and embryo development in gibberellin-induced pegs in *A. hypogaea* cv Robut 33-1 x *Arachis* sp. PI 276233.

Concentration (mg/1)	Day of treatment 10	15	20	25
	Pods/peg (%)[1], control = 16			
10	21	32	29	16
25	14	14	27	19
50	15	21	30	33
	Ovule length (mm), control = 2.3			
10	2.9	2.1	3.1	1.9
25	3.2	2.3	3.5	2.5
50	2.5	3.3	2.5	2.6
	Embryo length (mm), control = 0.27			
10	1.5	0.6	0.6	
25	2.6	1.0	1.5	0.6
50	1.0	0.9	0.9	0.6

1. Total pegs treated = 368; minimum number in any treatment = 22.

IAA = Indole acetic acid.

Table 52. Peg and pod production after gibberellin treatment in some intersectional crosses.

	Pollinations (no.)	Pegs (%)	Pods/ pegs (%)
Section *Arachis* x Section *Triseminale*			
A. duranensis (2n=20) x *A. pusilla* (2n=20)	33	79	39
A. hypogaea cv Robut 33-1 x *A. pusilla* (2n=20)	78	46	0
Section *Arachis* x Section *Erect aides*			
A. hypogaea cv Robut 33-1 x *A. rigonii* (2n=20)	45	64	13
A. hypogaea cv M 13 x *A. rigonii*	18	94	22
A. hypogaea cv TMV 2 x *A. rigonii*	43	86	26
Section *Arachis* x Section *Extranervosae*			
A. hypogaea cv Robut 33-1 x *A. villosullicarpa* (2n=20)	39	59	3
A. hypogaea cv MK 374 x *A. villosulicarpa* (2n=20)	9	89	11
Section *Extranervosae* x Section *Triseminale*			
A. villosulicarpa (2n=20) x *A. pusilla* (2n=20)	24	54	46
Section *Arachis* x Section *Rhizomatosae*			
A. hypogaea cv Robut 33-1 x *Arachis* sp. Coll. 9649	82	44	6
A. hypogaea cv Robut 33-1 x *Arachis* sp. Coll. 9797	46	57	2
A. hypogaea cv Robut 33-1 x *Arachis* sp. Coll. 9806	26	62	0
A. hypogaea cv TMV 2 x *Arachis* sp. PI 276233	408	76	20
A. hypogaea cv TMV 2 x *Arachis* sp Coll. 9649	11	73	0
A. hypogaea cv MK 374 x *Arachis* sp PI 276233	648	68	32
A. hypogaea cv MK 374 x *Arachis* sp Coll. 9649	26	42	15
A. hypogaea cv M 13 x *Arachis* sp PI 276233	75	56	5
A. hypogaea cv Chico x *Arachis* sp PI 276233	58	66	9
A. hypogaea cv Chico x *Arachis* sp. PI 9649	26	73	19

Table 54. Effect of IAA in lanolin (applied on day 15 after pollination) on pod-set and on ovule and embryo development in gibberellin-induced pegs *in A. hypogaea* cv MK 374 x *Arachis* sp. PI 276233.

Concen- tration (mg/1)	Pegs treated (no.)	Pods/ peg (%)	Ovule length (mm)	Embryo length (mm)
0	110	44	2.4	0.7
10	62	43	3.1	0.7
25	51	33	2.1	0.7
50	45	20	2.4	
100	34	29	2.6	0.8

Cooperation with AICORPO

Coordinated Yield Trials

During the 1982 rainy season, 10 yield trials sponsored by the All India Coordinated Research Project on Oilseeds (AICORPO) were conducted on Alfisols at ICRISAT Center. No supplementary irrigation nor protection against pests and diseases was provided. A drought in October and severe attacks of late leaf spot and rust caused low yields.

In the evaluation trial with Spanish bunch cultivars, 6 of the 10 ICRISAT lines included (ICGS Nos. 11, 15, 26, 30, 35, and 44) significantly outyielded the national check J 11 (Table 56), but only ICGS 35's yield was significantly higher than the local checks JL 24 and Robut 33-1.

In the trial with Virginia bunch cultivars, five of the eight ICRISAT entries outyielded the national check TMV 10. Cultivar CGC 6, a selection from ICRISAT breeding material supplied to a national breeder, significantly outyielded TMV 10 and Robut 33-1.

In the coordinated variety trial, the Spanish bunch lines ICGS I and CGC 2 significantly outyielded Robut 33-1, but none of the Virginia bunch entries was superior to Robut 33-1 (Table 57).

Rabi/Summer Yield Trial

In the 1981/82 postrainy season, 18 ICRISAT selections were evaluated for a second year at five sites in India to identify cultivars suitable for postrainy/summer conditions. Yields were low at most sites after poor crop establishment but at Latur, Maharashtra, five ICRISAT lines each yielded more than 7000 kg/ha of pods (Table 58). Based on their performances in this trial for

Table SS. Effect of kinetin in lanolin on pod-set and ovule and embryo development in gibberellin-induced pegs in *A. hypogaea* cv Robut 33-1 x *Arachis* sp. PI 276233.

Concentration (mg/1)	Day of treatetment 10	15	20	25
	Pods/poll (%), control = 16			
1	0	24	11	7
5	0	29	25	8
10	13	20	10	38
25	0	4	0	ND[1]
50	9	ND	11	ND
	Ovule length (mm), control = 2.3			
1		2.3	2.6	-[3]
5	NA	2.1	3.3	-
10	2.9	1.6	3.8	2.6
25	NA	-	NA	NA
50	-	NA	3.0	NA
	Embryo length (mm), control = 0.27			
1	NA	0.75	1.15	-
5	NA	1.63	0.93	-
10	0.91	0.4	1.42	1.1
25	NA	-	NA	NA
50	-	NA	0.52	NA

1. ND = Not done. 2. NA = None available.
3. Indicates ovule or embryo too small to dissect.

Table 56. Pod yields of selected entries from AICORPO initial evaluation trial, ICRISAT, rainy season 1982.

Spanish bunch cultivars		Virginia bunch cultivars	
Entries	Pod yield (kg/ha)	Entries	Pod yield (kg/ha)
ICGS 35	1490	CGC 6	1880
ICGS 30	1400	ICGS 46	1510
CGC 4	1400	ICGS 48	1490
ICGS 11	1290	ICGS 49	1450
ICGS 15	1220	ICGS 18	1310
ICGS 44	1220	ICGS 20	1300
ICGS 26	1190		
J 11 [a]	970	TMV 10[a]	860
JL 24 [b]	1200	Robut 33-1 [b]	1570
Robut 33-1 [b]	1190		
SE	±78		±91
CV (%)	14		14

a. National check cultivar.
b. Local check cultivars.

One of four ICRISAT groundnut selections that have reached the final stage of prerelease evaluation in India, based on performance in postrainy/summer yield trials.

2 years, ICRISAT selections ICGS 6, ICGS 11, ICGS 12, and ICGS 15 were promoted to the final evaluation trial at 22 locations in India in the 1982/83 postrainy season.

Foliar Diseases Resistance

Ten germplasm and breeding lines with resistance to rust and late leaf spot diseases and three

Table 57. Pod yields of selected entries from AICORPO coordinated variety trial, ICRISAT Center, rainy season 1982.

Spanish bunch cultivars		Virginia bunch cultivars	
Entries	Pod yield (kg/ha)	Entries	Pod yield (kg/ha)
ICGS 1	1100	ICGS 4	1170
CGC 2	1050	ICGS 5	1100
		ICGS 6	1100
J 11[a]	720	TMV 10[a]	740
Robut 33-1,[b]	870	Robut 33-1[b]	1100
SE	±51		±71
CV (%)	14		16

a National check cultivar.

b. Local check cultivar.

Table 58. Pod yields (kg/ha) of selected entries from AICORPO-1CR1SAT cooperative rabi/summer yield trials at five locations in India, postrainy season 1981/82.

Entries	Aliyarnagar	Dharwar	Junagadh	Latur	Vriddhachalam
ICGS 12	1180	3290	1350	8480	1070
ICGS 6	1760	3330	1930	7050	830
ICGS 11	1310	2490	1460	7770	1280
ICGS 19	1930	2130	1360	7020	1250
ICGS 18	1770	2280	1370	6190	1520
ICGS 37	1320	1560	1300	7380	1400
ICGS 34	1450	2650	810	6670	1150
ICGS 16	1060	2750	920	6820	1160
ICGS 27	780	3200	1370	6220	950
ICGS 15	1190	3250	1270	5830	610
J 11 [a]	990	3120	1180	4730	1170
Local check	980	3780	1850	3240	1350
Robut 33-1 [b]	1630	1300	1300	6820	1440
SE	±151	±511	±74	±202	±165
CV (%)	11	24	11	11	32

a. National check cultivar.
b. High-yielding released cultivar.

Table 59. Rust and late leaf spot reactions and pod and haulm yields of entries in the AICORPO-ICRISAT cooperative foliar diseases resistance variety trial, ICRISAT Center, rainy season 1982.

	Field disease score[a]		Yield (kg/ha)		Shelling
Entries	Rust	Late leaf spot	Pods	Haulms	(%)
ICG (FDRS)-1	3.0	7.0	1420	2780	66.5
ICG (FDRS)-2	3.0	5.5	1260	4170	67.8
ICG (FDRS)-3	4.0	4.3	1140	3000	68.7
ICG (FDRS)-4	4.0	6.3	1920	3170	65.7
ICG 1697	2.0	6.0	900	4890	65.6
ICG 7882	2.5	6.5	1210	4060	67.6
ICG 7898	3.0	5.5	940	4720	64.0
CGC 4002	3.0	7.8	1080	2220	63.1
CGC 4007	3.0	7.5	2000	3220	70.4
CGC 4018	3.0	7.5	2370	2670	64.5
J 11[b]	9.0	9.0	220	1820	65.1
Robut 33-1[c]	9.0	9.0	360	2670	70.7
JL 24[c]	9.0	9.0	240	1300	67.9

a. Scored on a 9-point scale: 1 = no disease and 9 = 50 to 100% foliage destroyed.
b. National check cultivar.
c. Local check cultivars.

released Indian cultivars were evaluated for their reactions to the two diseases and for pod and haulm yields at several locations in India. Results from the trial at ICRISAT Center are given in Table 59. Rust and late leaf spot attacks were severe at ICRISAT Center in 1982, and all the disease-resistant entries significantly outyielded the national and local controls.

Rhizobium Inoculation Trials

The *Rhizobium* strain NC 92 was tested as an inoculant for the cultivar Robut 33-1 at seven locations in India. The inoculant increased yield of Robut 33-1 at three of the seven locations (Table 60).

Table 60. Yield response (kg pod/ha) of groundnut cv Robut 33-1 to *Rhizobium* inoculation at seven locations in India, rainy season 1981.

AICORPO locations	Noninoculated control	NC 92	SE±
Durgapura	1060	1400	75
Jalgaon	1680	2230	72
Kadiri	1460	1370	73
Ludhiana	1560	1610	-
Tirupati	1400	1410	118
Junagadh	590	1260	51
ICRISAT	1300	1380	106

Source - AICORPO Groundnut annual progress report, Volume 1, May 1982. Directorate of Oil Seeds Research, Rajendranagar, Hyderabad.

Distribution of Breeding Material

In 1982 we supplied 463 breeding lines to workers in India and 3724 lines to workers in 30 other countries.

Looking Ahead

Diseases. Emphasis will continue on assessing breeding lines and material from the cytogenetics program for resistance to rust and leaf spot diseases. The recent establishment of our regional program in Malawi will provide excellent facilities for screening germplasm and breeding lines for resistance to early leaf spot, *Phoma* leaf disease, and rosette virus disease. We hope to become more involved with problems in eastern Asia and to increase our cooperative research there so that we might start projects on bacterial wilt and witches broom diseases—both serious problems in several countries of that region. We will continue to work on pod rots and the aflatoxin problem.

Pests. We will continue to screen germplasm lines for resistance to major groundnut pests, and being in Malawi will permit us to expand this work, particularly in research on the aphid vector of rosette virus.

Nitrogen fixation. We will examine responses to inoculation with *Rhizobium* strain NC 92 in more locations, including farmers' fields, and will study the competitive ability of this strain. We hope to develop equipment for liquid inoculation of groundnut seed. Further research will be carried out on techniques for measuring nitrogen fixation in the field. Patterns of nitrogen uptake and distribution in groundnut plants will be examined to see if symbiotic nitrogen fixation and nitrate reductase activity are limiting yields.

Physiology. Studies on drought physiology will continue and we will be expanding drought resistance screening of germplasm and breeding lines. Selections from the drought-screening trials will be tested in natural drought conditions in several locations. Studies on photoperiod effects will continue. Developing early-maturing cultivars with effective seed dormancy will continue to receive high priority.

Plant improvement. Our emphasis on breeding for stable disease and pest resistance, high yield, and earliness will continue. The cytogenetics program will help us accelerate breeding for resistance to late and early leaf spots by developing derivatives from interspecific crosses with good disease resistance and other qualities. The recent identification of resistance and tolerance to peanut mottle and clump virus diseases will allow us to start breeding for resistance to those diseases. Breeding for resistance to pod rots and to *Aspergillus flavus* will be intensified. Selection and breeding work, already commenced in our regional program in Malawi, will be intensified with special emphasis on breeding for resistance to rosette disease. We hope to increase our varietal assessment trials in various locations in Asia, Africa, and other SAT regions.

Wild species. We will continue to supply advanced stable lines with resistance to leaf spots, rust, and with other useful characters to plant breeders. The advanced stable lines and earlier-stage segregating materials will be made available to workers in other regions for selection under a wide range of environmental conditions. We shall continue with tissue culture techniques and hormonal treatments in efforts to use *Arachis* species with desirable characters now incompatible with cultivated groundnuts.

Publications

Journal Articles

ARUNACHALAM, V., BANDOPADHYAY, A, NIGAM, S.N., and GIBBONS, R.W. 1982. Heterotic potential of single crosses in groundnut *(Arachis hypogaeaL.).* Oleagineux 37:415-420.

HAMMONS, R.O., SUBRAHMANYAM, P., **RAO, V.R., NIGAM, S.N., and GIBBONS, R.W. 1982.** Registration of four peanut gcrmplasm lines resistant to rust (Reg. No. GP 18 to GP 21). Crop Science 22: 453.

HAMMONS, R.O., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N., and GIBBONS, R.W. 1982. Registration of eight peanut gcrmplasm lines resistant to rust (Reg. No. GP 22 to GP 29). Crop Science 22: 452-453.

HAMMONS, R.O., BRANCH, W.D., BROMFIELD, K.R., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N., GIBBONS, R.W., and GOLDIN, E. 1982. Registration of Tifrust-13 peanut gcrmplasm (Reg. No. GP 30). Crop Science 22: 697.

HAMMONS, R.O., BRANCH, W.D., BROMFIELD, K.R., SUBRAHMANYAM, P., RAO, V.R., NIGAM, S.N., and GIBBONS, R.W. 1982. Registration of Tifrust-14 peanut gcrmplasm (Reg. No. GP 31). Crop Science 22: 697-698.

MEHAN, V.K., McDONALD, D., and GIBBONS, R.W. 1982. Seed colonization and aflatoxin production in groundnut genotypes inoculated with different strains of *Aspergillus flavus.* Oleagineux 37:185-191.

NAMBIAR, P.T.C. 1982. Grafting studies on non-nondulating groundnut. Tropical Grain Legume Bulletin. 26: 21-24.

NAMBIAR, P.T.C, DART, P.J., SRINIVASA RAO, B., and RAMANATHA RAO, B. 1982. Nodulation in the hypocotyl region of groundnut *(Arachis hypogaea).* Experimental Agriculture 18:203-207.

NEVILL, D.J. 1981. Components of resistance to *Cercospora arachidicola* and *Cercosporidium personatum* in groundnuts. Annals of Applied Biology 99: 77-86.

NEVILL, D.J. 1982. Inheritance of resistance to *Cercosporidium personatum* in groundnuts: a genetic model and its implications for selection. Oleagineux 37 (7): 355-366.

SASTRI, D.C., and MOSS, J.P. 1982. Effects of growth regulators on incompatible crosses in the genus *Arachis* L. Journal of Experimental Botany 33: 1293-1301.

SINGH, A.K., and MOSS, J.P. 1982. Utilization of wild relatives in genetic improvement of *Arachis hypogaea* L. Part 2: Chromosome complements of species in section *Arachis.* Theoretical and Applied Genetics 61: 305-314.

SREENIVASULU, P., IIZUKA, N., RAJESHWARI, R., REDDY, D.V.R. and NAYUDU, M.V. 1981. Peanut green mosaic virus—a member of the potato virus Y group infecting groundnut *(Arachis hypogaea)* in India. Annals of Applied Biology 98: 255-260.

SUBRAHMANYAM, P., McDONALD, D., and GIBBONS, R.W. 1982. Variation *in Cercosporidium personatum* symptoms on certain cultivars of *Arachis hypogaea.* Oleagineux 37: 63-68.

SUBRAHMANYAM, P., and McDONALD, D. 1982. Groundnut rust—its survival and carry-over in India. Proceedings of the Indian Academy of Sciences (Plant Science) 91: 93-100.

SUBRAHMANYAM, P., McDONALD, D., SIDDARAMAIAH, A.L., and HEGDE, R.K. 1981. Leafspot and veinal necrosis disease of groundnut in India caused by *Alternaria alternata.* FAO Plant Protection Bulletin 29: 74-76.

SUBRAHMANYAM, P., McDONALD, D., GIBBONS, R.W., NIGAM, S.N., and NEV1LL, D.J. 1982. Resistance to both rust and late leafspot diseases in some genotypes of *Arachis hypogaea.* Peanut Science 9: 6-10.

Conference Papers

McDONALD, D., and MEHAN, V.K. 1982. Post-harvest programme in ICRISAT. Presented at the Workshop on Post Harvest Losses and Small Farmer Storage for South Asia and ECS Africa, Commonwealth Secretariat and Government of India, 19-24 Apr 1982, New Delhi, India.

MEHAN, V.K., and McDONALD, D. 1982. Mycotoxin-producing fungi in groundnuts- potential for mycotoxin contamination. Pages 98-101 *in* Proceedings, International Symposium on Mycotoxins and Phytotoxins, the International Union of Pure and Applied Chemists, 1-3 Sept 1982, Vienna, Austria.

MUNIYAPPA, V., and REDDY, D.V.R. 1982. Transmission of cowpea mild mottle virus by *Bemisia tabaci* in a non-persistent manner. Page 41 *in* Proceedings of the All India Symposium on Vectors and Vector-Borne Diseases, Indian Council of Medical Research, 26-28 Feb 1982, Trivandrum, Kerala, India.

MOSS, J.P., and SASTRI, D.C. 1982. Wide hybridisation in *Arachir.* problems and prospects. Presented at the International Symposium on New Genetical Approaches to Crop Improvement, organized by the Pakistan Atomic Energy Agricultural Research Centre, 6-10 Feb 1982, Karachi, Pakistan.

NAMBIAR, P.T.C., NIGAM, S.N., DART, P.J., and GIBBONS, R.W. 1982. Genetic manipulation of nodulation in groundnut. Pages 49-56 *in* Biological nitrogen fixation technology for tropical agriculture, (eds. P.H. Graham and S.C. Harris). Papers presented at a workshop held at CIAT, 9-13 Mar 1981, Cali, Colombia, Centro Internacional de Agricultural Tropical.

NAMBIAR, P.T.C., DART, P.J., SRINIVASA RAO, B., and RAVISHANKAR, H.N. 1982. Response of groundnut *(Arachis hypogaea)* to inoculation. Ibid, pp 241-248.

NAMBIAR, P.T.C., RAO, MR., REDDY, M.S., FLOYD, C, DART P.J., and WILLEY, R.W. 1982. Nitrogen fixation by groundnut *(Arachis hypogaea)* in intercropped and rotational systems. Ibid, pp 647-652.

SASTRI, D.C, MOSS, J.P., SINGH, A.K., and NALINI, M. 1982. Groundnut tissue culture research at ICRISAT. Presented to the Tissue Culture discussion group at the XIV Meeting of the American Peanut Research and Education Society, July 1982, Albuquerque, USA.

SINGH, A.K., and MOSS, J.P. 1982. Improvement of *Arachis hypogaea* by combining ancestral and other wild species genomes. Page 70 *in* Proceedings of the XIV Meeting of the American Peanut Research and Education Society, July 1982, Albuquerque, USA.

WILLIAMS, J.H. 1982. Genetic manipulation for improving crop production in stress environments, a physiologist's viewpoint. Presented at the 75th Anniversary Celebration of Tamil Nadu Agricultural University, Apr 1982, Coimbatore, India.

FARMING SYSTEMS

Contents

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FARMING SYSTEMS

Our pursuit of improved management systems for the SAT, the major aim of the Farming Systems Research Program, has resulted in a double cropping system for deep Vertisols for the assured rainfall areas in India; this system has considerable promise for substantially improving productivity and reducing resource degradation of these soils. The main feature of the new system is replacing the single annual crop with two high-yielding crops that improve productivity and stability.

Developing the improved management system involved better defination of the methodologies for farming systems research (FSR). To discuss and summarize these concepts, a special in-house review was conducted at ICRISAT Center in March 1981. The review substantially crystalized our major research approach, which is a combination of several activities, as follows:

1. Resource evaluation, involving primary data on the SAT and synthesizing secondary data, where necessary.
2. On-station research involving component research, interdisciplinary research, and operational research in successive steps as each improved system is developed.
3. On-farm research including exploratory surveys, diagnostic experiments, and evaluating prospective technologies and technology adoption by farmers.

FSRP work conducted during 1982 is reported under these major activity headings.

Resource Evaluation

Resource evaluations are of two types: first, compiling information on environmental resources (soil, water, light, nutrients, genotypes) of the SAT; second, determining the ranking of resources by discipline-orientated experiments. Our work in the first category mainly involves better description of the agroclimate; many FSR disciplines conduct studies in the second category. In ICRISAT's Annual Report 1981 we described the climatic environment of pigeonpea. This year we are reporting similar agroclimatic studies for sorghum.

Sorghum in Semi-Arid Tropics (SAT)

India produces the most sorghum of any country in the world, 34% of the total SAT production. West Africa, East Africa, and Southern Africa together contribute 27%. Sorghum expresses itself well in the physical environment of these regions, so we attempted to describe such properties of the environment as radiation, rainfall, temperature, and soils.

Environment of Africa's SAT Sorghum-growing Areas

The mean annual solar radiation in Africa's SAT ranges from 400 to 500 Cal/cm^2 per day, with highest amounts along the northern and southern boundaries.

Daily mean maximum temperatures in SAT Africa (Table 1) are consistently high during the growing season with relatively small variation, especially near the equator. In general, air temperatures are lowest in August, also the wettest month of the year. The intertropical convergence zone (ITCZ) causes rainfall isohyets in West Africa to run parallel with the equator with rain increasing with distance south.

On the dry north side of the area, the decrease in rainfall with latitude is most pronounced in Niger, where the rainy season is short and the dry season severe. Variability in annual rainfall increases with aridity from south to north.

Moisture-availability indices (MAI, as defined by Hargreaves 1975) during the

Table 1. Mean maximum and minimum air temperature (°C) during the growing season at indicated locations in Africa.

Location	Latitude (N) °	June	July	Aug	Sept	Oct	Nov
Accra	05 36	28.9 [a]	27.3	27.2	28.5	29.6	30.9
(Ghana)		22.6 [b]	21.8	21.3	21.8	22.3	22.8
Navrongo	10 53	32.7	30.7	29.6	30.6	33.4	35.9
(Ghana)		23.2	22.5	22.3	21.9	21.9	20.1
Bobo Dioulasso	11 10	31.8	30.1	29.5	30.7	32.8	34.4
(Upper Volta)		21.3	20.7	20.6	20.4	20.6	19.2
Kano	12 03	33.6	30.4	29.2	30.9	33.9	33.7
(Nigeria)		22.5	21.1	20.8	20.9	19.8	16.0
Ouagadougou	12 21	33.1	31.2	30.3	31.8	35.6	36.9
(Upper Volta)		22.9	22.2	21.4	21.3	21.8	20.0
Sokoto	13 01	35.4	31.5	29.9	31.4	34.7	35.4
(Nigeria)		24.1	22.1	21.4	21.5	21.0	17.8
Maradi	13 28	36.7	32.3	30.6	32.1	35.9	35.5
(Niger)		23.8	22.0	21.1	21.5	19.3	15.4
Niamey	13 29	36.7	33.2	31.3	33.0	37.2	37.2
(Niger)		25.1	23.2	22.5	22.7	23.0	19.0

a. Mean maximum air temperature.
b. Mean minimum air temperature.

sorghum-growing season at selected locations in semi-arid Africa are shown in Table 2. In West Africa, moisture for sorghum is fairly adequate till September but is highly undependable in October and November. The adequate period ranges from 90 days on the northern boundary of SAT Africa to 270 days in southern regions of Ghana, Nigeria, and Sudan. Medium growing periods (150-210 days) are common throughout Africa's SAT sorghum-growing areas.

Environment of Sorghum-growing Areas in India

From the 1979/80 area and production data, we estimated that of the total sorghum area of 16.4 million hectares, 60% is cropped to rainy-season sorghum (*kharif* crop) and 40% to postrainy-season sorghum (*rabi* crop). Yields are slightly higher for the rainy season crop.

The Indian SAT produces more than 99% of the sorghum grown in India. The variation in average maximum and minimum temperatures, computed from 25 representative stations for each of the rainy and postrainy seasons, and average dates of anthesis and physiological maturity for CSH-6 (a rainy-season hybrid) and CSH-8-R (a postrainy-season hybrid) are shown in Figure 1.

The diurnal range in temperature is narrow and temperatures are uniformly high in the rainy season; such temperatures should promote good

Table 2. Moisture availability index (MAI) during the sorghum-growing season at representative locations in semi-arid Africa.

Location	Moisture availability index (MAI)					
	June	July	Aug	Sept	Oct	Nov
North of equator						
Ouagadougou (Upper Volta)	0.47	1.00	1.47	0.75	0.06	0.00
Kano (Nigeria)	0.48	1.07	1.76	0.59	0.00	0.00
Geneina (Sudan)	0.07	0.67	1.36	0.29	0.00	0.00
	Dec	Jan	Feb	Mar	Apr	May
South of equator						
Inhambane (Mozambique)	0.37	0.32	0.36	0.36	0.36	0.31
Livingstone (Zambia)	0.62	0.80	0.55	0.29	0.03	0.00

vegetative growth and grain filling. In the postrainy season the diurnal range in temperature, especially around flowering, is wide and minimum temperatures are consistently low.

Average rainfall isohyets superimposed on the sorghum-growing areas showed that rainfall varies from 700 mm to 1400 mm. Almost all the rainy-season core areas are in the 800 to 1000

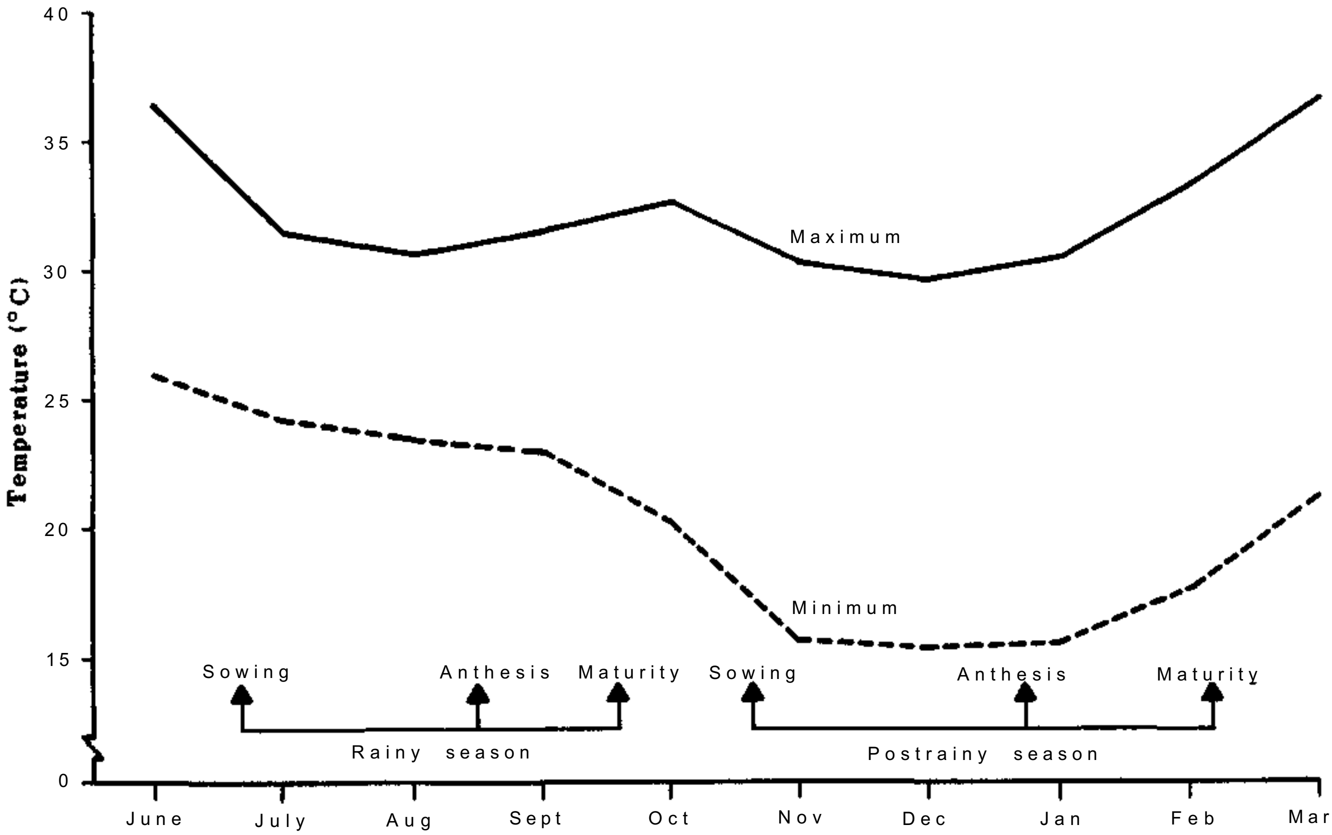


Figure 1. Maximum and minimum air temperatures during the rainy and postrainy seasons in SAT India (1931-1960).

Table 3. Moisture availability index (MAI) in the rainy months of sorghum-growing areas at representative locations in semi-arid India.

Sorghum-growing season	Location	June	July	Aug	Sept	Oct
Rainy	Nagpur	0.74	2.54	1.64	0.73	0.07
	Indore	0.25	1.44	1.13	0.67	0.03
	Hyderabad	0.31	0.76	0.66	0.88	0.15
	Akola	0.38	1.10	0.60	0.60	0.03
Postrainy	Ahmednagar	0.40	0.34	0.23	0.67	0.13
	Sholapur	0.38	0.41	0.41	0.72	0.13
	Chitradurga	0.24	0.37	0.34	0.47	0.40

mm rainfall range. The postrainy-season core areas are mostly in the belt with less than 800 mm of undependable rainfall.

The moisture availability index (MAI)—based on representative locations—is consistently higher in the rainy-season sorghum-growing areas than in the postrainy-season sorghum-growing areas during the peak growth period of July and August (Table 3). The low MAIs at Sholapur, Ahmednagar, and Chitradurga provided a reason for the farmers' practice of cropping there only in the postrainy season.

Crops' Efficiency in Converting Intercepted Radiation

Sorghum

During the rainy season we grew three sorghum genotypes (CSH-1, CSH-6, and SPV-351) on Alfisols under uniform management. We sowed them 24 June and they emerged 28 June. We used four quantum sensors and read-out integrators to measure intercepted photosynthetic photon flux density (PPFD) at regular intervals throughout the growing season.

Slopes of the regression relationship between dry matter produced and intercepted PPFD for the three sorghum genotypes were 2.7 ± 0.09 g/ MJ for CSH-1, 3.1 ± 0.05 for CSH-6, and 2.5 ± 0.04 for SPV-351. Growth efficiencies calculated from b values and a calorific value of 17 KJ/g were 4.7, 5.4, and 4.4% for CSH-1, CSH-6, and SPV-351, respectively. Hybrid CSH-6 has shown highest growth efficiencies during the growing season over the past 3 years.

Millet

We grew three millet genotypes (BJ 104, WC-C75, and ICMS 7703) on an Alfisol during the rainy season, sowing them 3 July after the profile was fully recharged. They emerged 7 July.

The relationship between intercepted PPFD and dry matter produced for WC-C75 is shown in Figure 2. The efficiency of conversion before anthesis was 4.0 ± 0.11 g per MJ, while after anthesis it was 1.6 ± 0.46 g per MJ. Growth efficiencies were calculated for millet as described for sorghum. Calculated growth efficiency for both BJ-104 and ICMS-7703 was 6.3%, but only 5.4% for WC-C75.

Pigeonpea/ Groundnut

We conducted a detailed growth study on pigeonpea/groundnut intercropping on an Alfisol in 1982 because of evidence that this combination can produce good yields over a wide range of crop proportions. We grew each crop alone in 30-cm rows, two intercrop treatments of one row pigeonpea: three rows of groundnut, and one row of pigeonpea:five rows of groundnut. Plant populations of each intercrop were at sole-crop optimums. Groundnut cv

Studying light interception and water use (measured here by neutron probe) in a pigeonpealgroundnut intercrop showed no significant differences overall between sole crops and the intercrop. Variations were noted, however, at different stages of growth; these will be studied further.

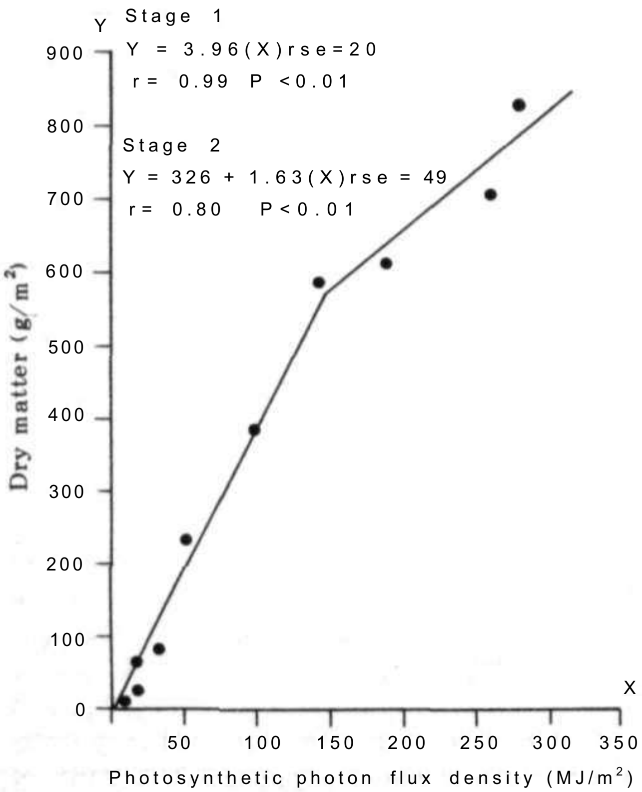


Figure 2. Relationship between dry matter and intercepted PPFD for WC-C75, ICRISAT Center, rainy season 1981.

Robut 33-1 was harvested 95 days after it emerged; pigeonpea cv ICP-1 after 175 days.

Because groundnut grows rapidly, both intercrop systems intercepted light fairly efficiently in the early stages, similar to sole groundnut. Growth and light interception of sole pigeonpea were slow up to 80 days after sowing; later light interception was much higher than by pigeonpeas in the two intercrop systems, especially after groundnut harvest (Fig.3). The 1:3 intercrop system was only 3% more efficient in converting light energy into dry matter, and the 1:5 intercrop system was 1 % less efficient than either sole crop. There was no evidence that water was used more efficiently in intercropping or that lack of water limited yield in this particularly wet season.

Water

Response of Groundnut to Drought Stress

Groundnut yields in the SAT vary widely because of erratic rainfall but information is meager on groundnut response to drought stress at different phenological stages. Cooperating scientists from Agroclimatology, Environmental Physics, Land and Water Management, and Groundnut Physiology subprograms conducted a multidisciplinary experiment during the postrainy seasons of 1980/81 and 1981/82 to investigate effects of different moisture stresses on the growth, plant-water relations, and yields of groundnuts.

To create a range of water-stress treatment, we used line-source sprinkler irrigation. The experiment was on a well drained, medium-deep Alfisol with an estimated total moisture-holding capacity of 254 mm in a 127-cm deep profile. Groundnut cv Robut 33-1 was sown 8 November both seasons and it emerged 14 November both seasons. Treatments imposed on the crop were:

1. Line-source irrigations at 5 and 15 days after crop emerged (DAE) followed by 30 days' stress to initiation of pegging; then no stress.
2. No stress to first flush of flowering (35 DAE); line-source irrigation, then stress from flowering to last pod set; then no stress.
3. No stress until first kernel appears (87 DAE); line-source irrigation, then stress imposed from pod filling to maturity.
4. Continuous stress imposed by line source every 10 days.

The irrigation schedule adopted in each season was the same except that two additional line-source irrigations were given treatment 3 in 1981/82 because evaporation was so high during March the previous year that even groundnuts near the line source were irreversibly stressed.

In each treatment, groundnut rows extended perpendicular to the line source up to 18 m on either side. Considering the amount of water applied as a function of distance from line source, we made all measurements 3, 9, and 15 m from the line (subtreatments A, B, and C in each main treatment).

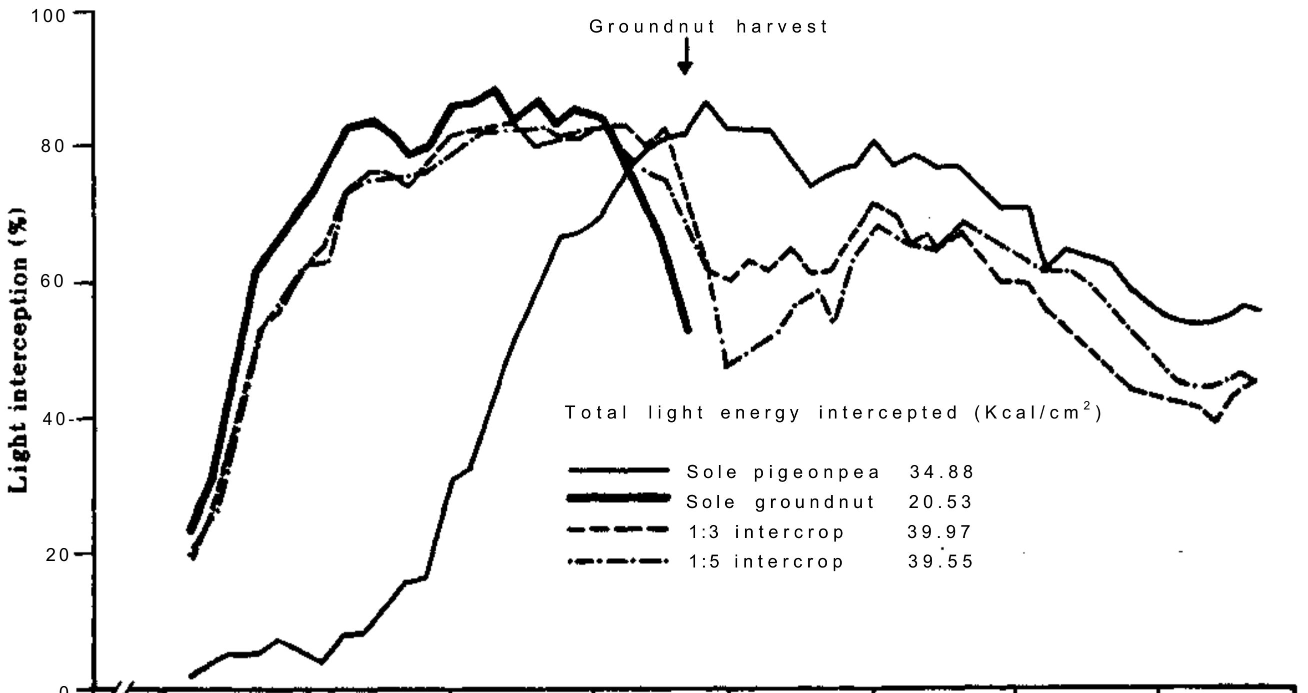


Figure 3. Light interception by pigeonpea and groundnut in indicated cropping arrangements on an Alfisol, ICRISAT Center, 1982.

Table 4. Seasonal changes in the stomatal conductance (cm/sec) of groundnut measured in different treatments,[1] ICRISAT Center, 1981/82.

		Treatment 1			Treatment 2			Treatment 3			Treatment 4			
Date	DAE	A	B	C	A	B	C	A	B	C	A	B	C	SE
15 Dec	30	0.63	0.83	0.19	0.73	0.73	0.73	0.73	0.73	0.73	0.81	0.73	0.56	±0.141
15 Jan	61	1.21	1.26	0.88	0.35	0.17	0.14	1.20	1.20	1.20	1.11	0.38	0.26	±0.123
2 Feb	79	1.24	1.28	1.10	0.15	0.16	0.08	1.28	1.28	1.28	1.18	0.51	0.10	±0.092
4 Feb	81	1.46	1.26	1.21	0.11	0.08	0.05	1.52	1.52	1.52	1.63	0.23	0.10	±0.073
5 Mar	110	1.39	1.26	1.28	1.36	1.18	0.11	0.91	0.06	0.02	1.37	0.13	0.10	±0.061
23 Mar	128	1.04	1.09	0.83	1.60	1.33	0.14	0.07	0.03	0.02	0.93	0.06	0.10	±0.073
5 Apr	141	0.76	1.01	0.26	0.84	0.83	0.88	0.31	0.03	0.01	0.31	0.08	0.07	±0.076
13 Apr	149	1.10	1.01	0.90	1.11	1.09	0.74	0.15	0.05	0.01	0.96	0.76	0.15	±0.056

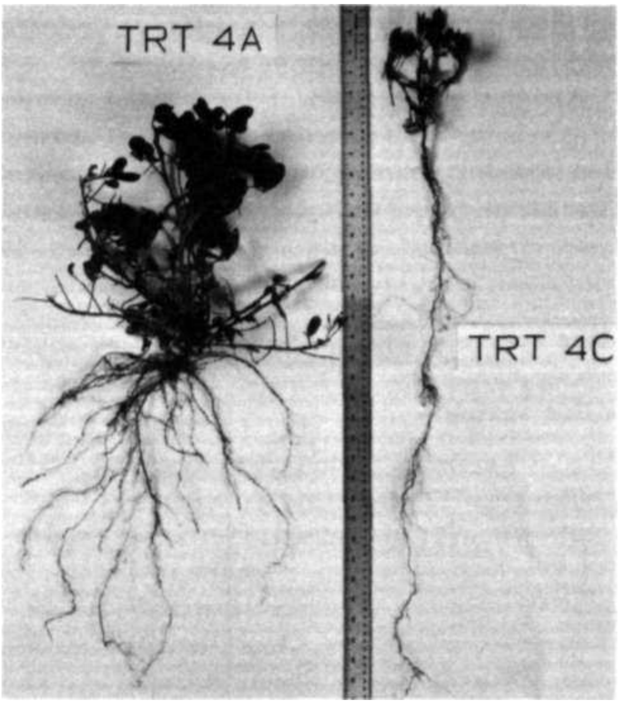
DAE = Days after emergence.

1. Treatment 1. Line source irrigation at 5 and 15 days after crop emerged (DAE), followed by 30 days stress to initiation of pegging; then no stress.
Treatment 2. No stress to first flush of flowering (35 DAE) line source irrigation, then stress from flowering to last pod set; then no stress.
Treatment 3. No stress to first kernel (87 DAE); line source irrigation, then stress imposed from pod filling to maturity.
Treatment 4. Continuous stress imposed by line source every 10 days.
Letters A, B, and C in each treatment refer to distances of 3, 9, and 15 m from the line source.

Table 5. Seasonal changes in the transpiration ($\mu g/cm^2$ per sec) of groundnut measured in different treatments,[1] ICRISAT Center, 1981/82.

		Treatment 1			Treatment 2			Treatment 3			Treatment 4			
Date	DAE	A	B	C	A	B	C	A	B	C	A	B	C	SE
15 Dec	30	9.55	12.28	4.34	11.04	11.04	11.04	11.04	11.04	11.04	12.31	10.51	7.51	±1.774
15 Jan	61	17.43	17.27	11.19	7.24	4.20	3.27	17.54	17.54	17.54	16.78	7.62	5.76	±1.236
2 Feb	79	16.42	14.93	11.61	3.40	3.85	2.10	20.32	20.32	20.32	18.50	9.32	2.64	±0.988
4 Feb	81	21.38	20.07	14.62	3.29	2.66	1.81	26.21	26.21	26.21	26.9	6.29	3.33	±1.045
5 Mar	110	22.55	20.06	18.92	24.38	23.17	4.43	21.97	2.75	1.06	26.13	4.50	3.59	±1.051
23 Mar	128	21.24	20.18	7.83	25.79	22.74	4.98	2.68	1.29	0.30	21.39	2.47	3.84	±1.113
5 Apr	141	23.78	27.63	8.12	24.74	24.08	25.24	11.59	1.12	0.20	15.10	3.46	3.47	±1.952
13 Apr	149	19.37	17.39	11.84	19.67	19.95	16.00	5.15	1.70	0.10	23.47	18.20	4.73	±0.906

1. For details of treatments, see fn 1. Table 4.



Studying groundnut response to moisture treatments at different stages of growth, our scientists found distance from the line source to be a key factor. Here are two plants subjected to the same stress treatments, but placed 3 m (left) and 15 m from the sprinkler. ICRISA T has evolved a multidisciplinary approach to study drought stress, recognizing how meager and vitally important such information is in the SATs erratic rainfall conditions.

Changes in stomatal conductance indifferent treatments are shown in Table 4. Measurements made 15 December reflect drought stress in treatment 1. Treatment 1C showed the lowest stomatal conductance (0.19 cm/sec). Treatment 4C, which received little water during three line source irrigations before 15 December, showed 0.56 cm/sec stomatal conductance. Stomatal conductance differed significantly only for treatment 1C.

Seasonal changes in groundnut transpiration rates in different treatments are shown in Table 5.

Atmospheric factors such as vapor-pressure deficit cannot be ignored as important modifiers of relationships between drought stress and transpiration and such associated plant reactions as stomatal conductance. Saturation deficits were monitored over treatments with psychrometers. Close to the line source (treatment 4A where 725 mm of water was applied), transpiration rates showed no reduction even up to a saturation deficit of 10 mb (Fig.4). In treatment 4B where the crop received only 379 mm of water, transpiration increased with saturation deficit up to 5 mb. Further saturation deficits decreased transpiration.

Groundnut yields from the different treatments during the two growing seasons are given in Figure 5. The line-source irrigation technique helped us impose a range of drought stresses indicated by decreased yields with distance from the line source. The data show that groundnut's most sensitive stage of growth is pod filling, with the active flowering stage next most sensitive. Drought during active flowering reduces the number of flowers, and flowers produced later

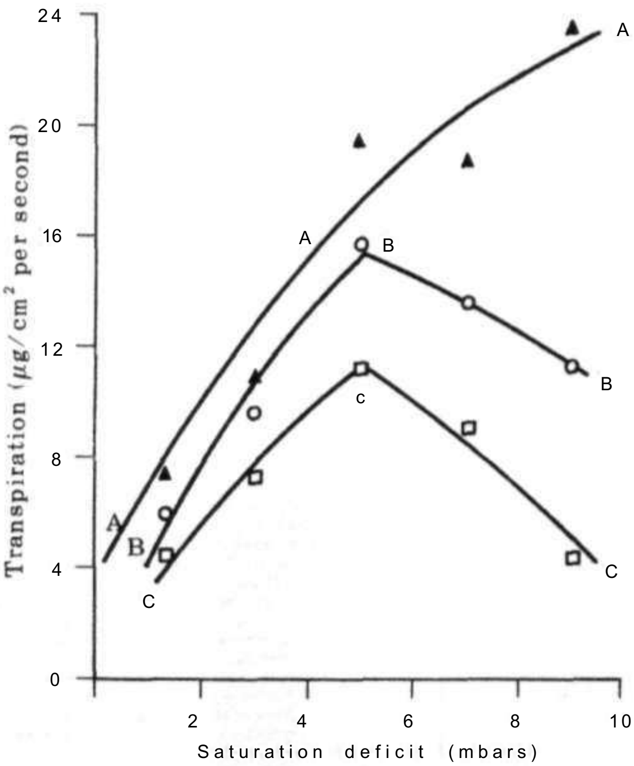


Figure 4. Transpiration from groundnut related to the saturation deficit of air. Treatments refer to groundnut grown on an Alfisol, ICRISAT Center, 1982. (A) 3 m from the line source, (B) 9 m from the line source, and (C) 15 m from the line source.

do not form pods effectively. Delay in flowering leads to a large reduction in capacity to form pods. Stress during gynophore elongation causes a dry surface soil, which prevents plant penetration into the soil and pod filling. Then calcium uptake by stressed gynophores in the soil may not be adequate, which leads to reduced pod formation and poor kernel filling.

A significant feature of the yield responses (Fig.5) is the yield increase in treatment 1 (3 and 9 m from line source) compared with the control (treatment 4A). Treatment 1A received 94 and

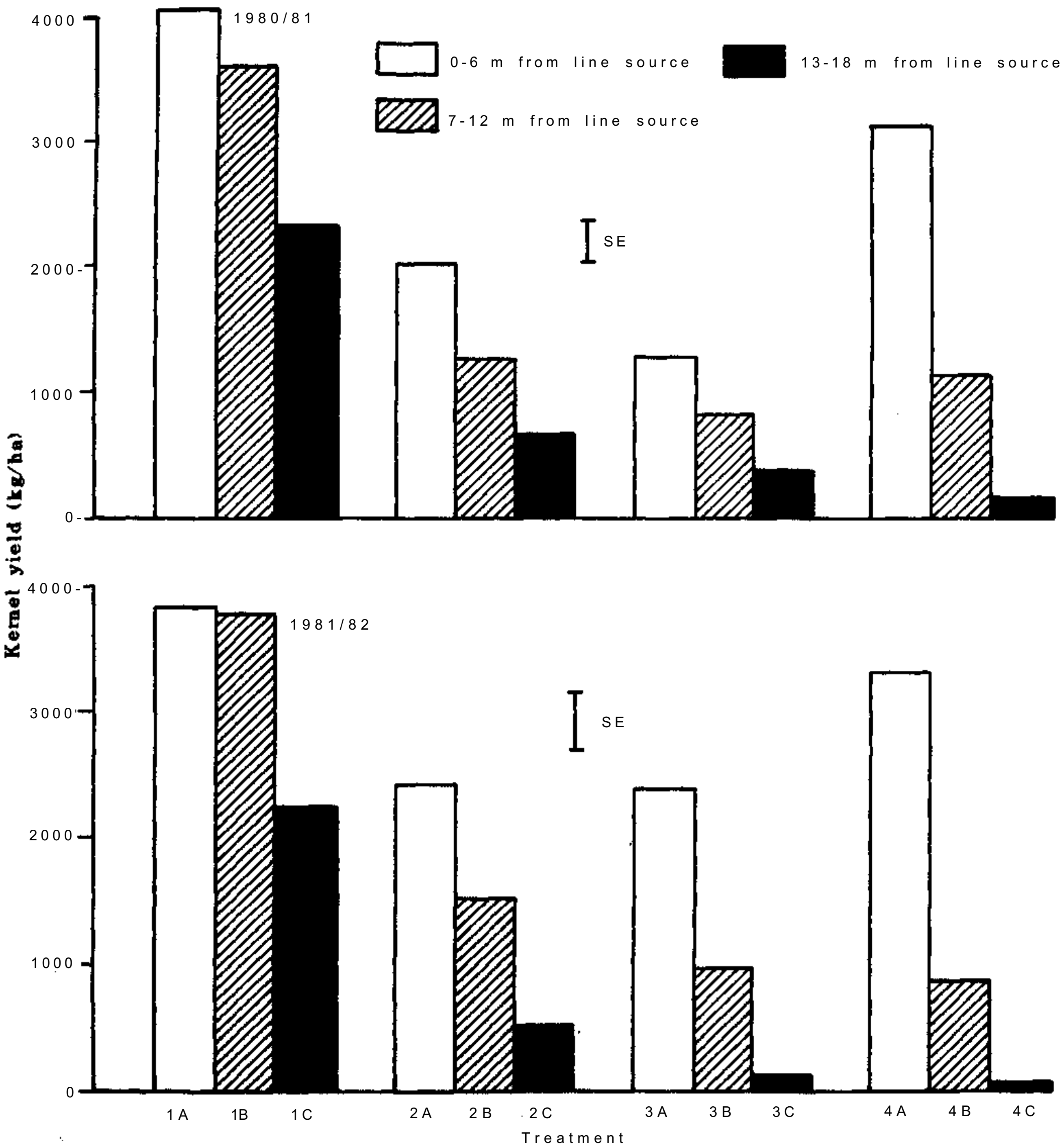


Figure 5. Yield response of groundnut to drought stress, Alfisol, ICRISAT Center, 1980/81 and 1981/82.

147 mm, and treatment 1B, 87 and 123 mm less than treatment 4A during the 1980/81 and 1981/82 growing seasons but 1A and 1B yielded 13 to 30% more than 4A.

A significant stimulus from stress relief may have increased flowers during the active flowering period. Also gynophore production was insensitive to early drought.

Seasonal groundnut evapotranspiration was computed with the water-balance equation:

$$ET = (Mi - Mf) + (1 + P) - (R + D)$$

where

ET = Seasonal evapotranspiration,
Mi = Initial moisture in 0- to 127-cm profile,
Mf = Final moisture in 0-to 127-cm profile,
I = Irrigation,
P = Precipitation,
R = Runoff, and
D = Deep drainage, deeper than 127 cm (considered negligible).

The technique we used helped us simulate a wide range of seasonal ET values—from 176 mm to 831 mm (Table 6). Highest grain yields were from subtreatment 1A, although seasonal ET values were highest in 4A. Highest water-use efficiency was in subtreatment 1B both years (Figs.6 and 7); in it water equivalent to 0.4 pan evaporation was applied during groundnut emergence, then no more water until initiation of pegging, then full irrigation (0.8 pan evaporation at 10-day intervals). Apparently drought stress during the vegetative stage benefits groundnuts.

Response of Chickpea to Drought Stress

Chickpea, India's most important pulse crop, is grown during the postrainy season on conserved moisture without irrigation; at times it suffers from drought stress. The sequence of different degrees ofdrought stress as the crop grows determines chickpea yields.

To quantify chickpea response to drought stress and predict the effect of stress on yield, we conducted an experiment using multiple sowing dates, different irrigation treatments, and two chickpea varieties on a deep Vertisol with 500-mm water-holding capacity.

Results from the two chickpea genotypes for

Table 6. Effect of drought stress on seasonal ET and grain yields of groundnut, ICRISAT Center.

	Seasonal evapotranspiration (mm)		Grain yield (kg/ha)	
Treatment[1]	1980/81	1981/82	1980/81	1981/82
1-A	734.6	778.3	4100	3830
1-B	647.0	738.8	3650	3790
1-C	614.3	753.1	2370	2230
2-A	671.9	678.2	2040	2450
2-B	574.6	604.9	1270	1520
2-C	482.5	516.0	690	540
3-A	662.5	643.2	1280	2400
3-B	594.1	543.8	820	960
3-C	529.4	440.8	380	130
4-A	807.3	831.1	3150	3340
4-B	470.2	517.0	1150	870
4-C	176.1	231.3	180	40
SE	±14.80	±11.28	±177	±377

1. For details of treatments, see Table 4. fn. 1.

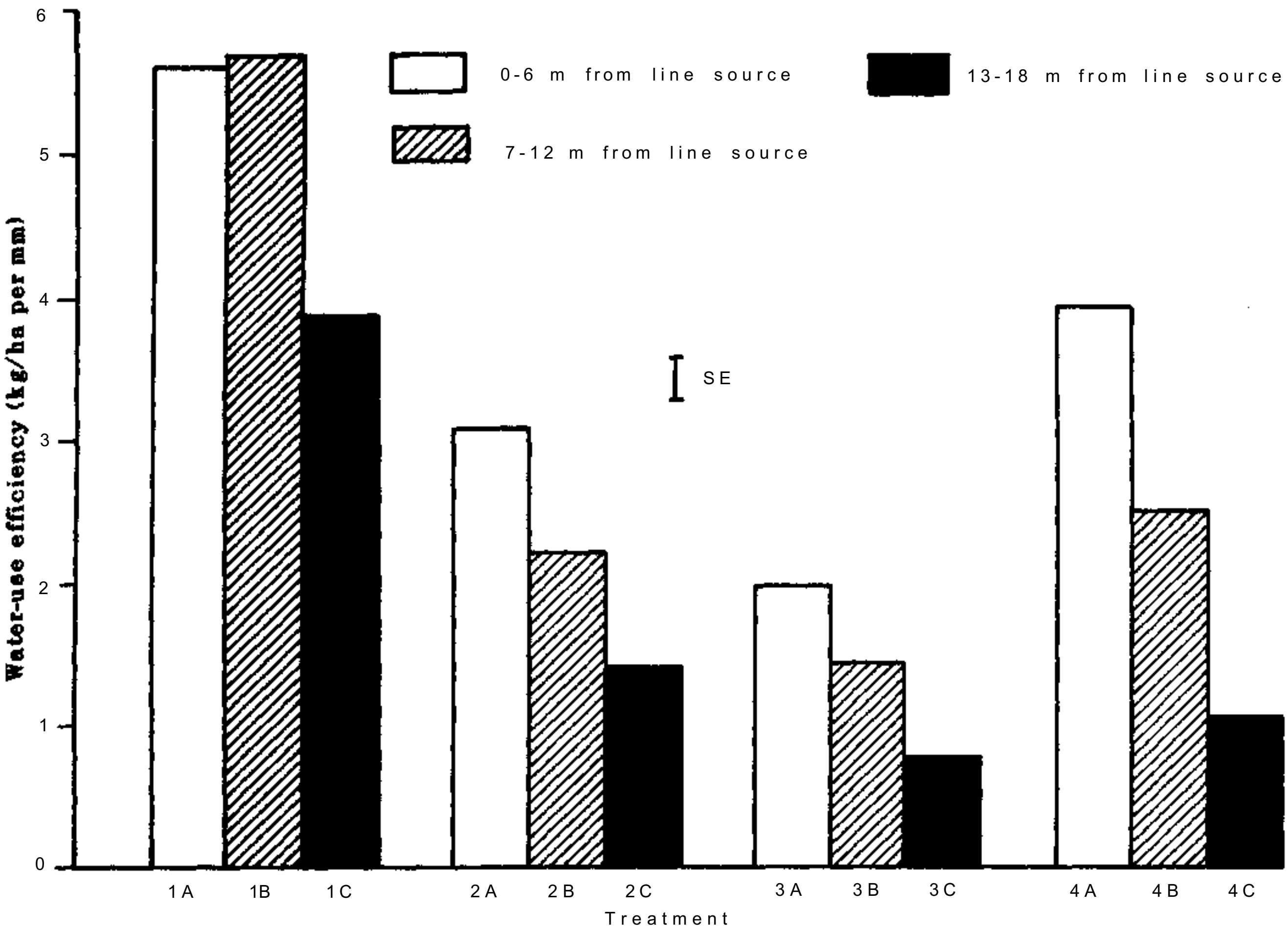


Figure 6. Effects of different drought stresses on water-use efficiency of groundnut (Robut 33-1), Alfisol, ICRISAT Center, 1980/81.

both seasons are shown in Tables 7 and 8. During the 1980/81 growing season, yields of nonirrigated chickpea planted at four dates did not differ significantly. But when Annigeri planted before 30 November received two or four irrigations, it yielded significantly more than when planted 30 November. L-550, however, responded only to the two-irrigation treatment.

Seasonal changes in dry-matter distribution of the two genotypes were monitored both seasons; dry-matter distribution data for two planting dates for 1980/81 growing season are shown in Figure 8. Supplemental irrigations markedly increased total dry matter. The data show strong interaction between irrigation and planting dates, as already discussed earlier under seed yield.

Providing supplemental irrigations to such indeterminate crops as chickpea increases vegetative growth and delays maturity. Delaying maturity for early plantings may increase water use and seed yields. Low night temperatures during December and January (Fig.9) may reduce yields from late plantings by causing flowers to abort.

The drought-induced stomatal closure in nonirrigated chickpea decreased leaf-water potential, which increased canopy temperature above air temperature; that led to what Idso et al. (1970) defined as stress degree days (SDD). $SDD = \sum_{i=1}^{N} (TC-TA)_i$, where TC is the canopy temperature; TA, the air temperature; and N, days data were recorded.

Table 7. Seed yield response (kg/ha) of two chickpea genotypes to irrigation[1], and dates of planting, ICRISAT Center, postrainy season 1980/81.

Planting date	Annigeri			L-550		
	I_0	I_1	I_2	I_0	I_1	I_2
15 Oct	1100	2020	2640	700	1810	1620
30 Oct	720	1960	2720	730	1610	2060
15 Nov	980	1990	2150	570	1490	1490
30 Nov	1030	1150	2100	630	1190	1740

1. I_0 = no irrigation; I_1 = two irrigations, 30 and 70 days after sowing; I_2 = four irrigations, 30, 50, 70, and 90 days after sowing.

SE for comparing irrigation x date x variety means, ±248.

SE for comparing date x variety means at same level of irrigation, ±237.

SE for comparing variety means at the same level of irrigation x date, ±234.

SE for comparing date means at the same level of irrigation x variety, ±237.

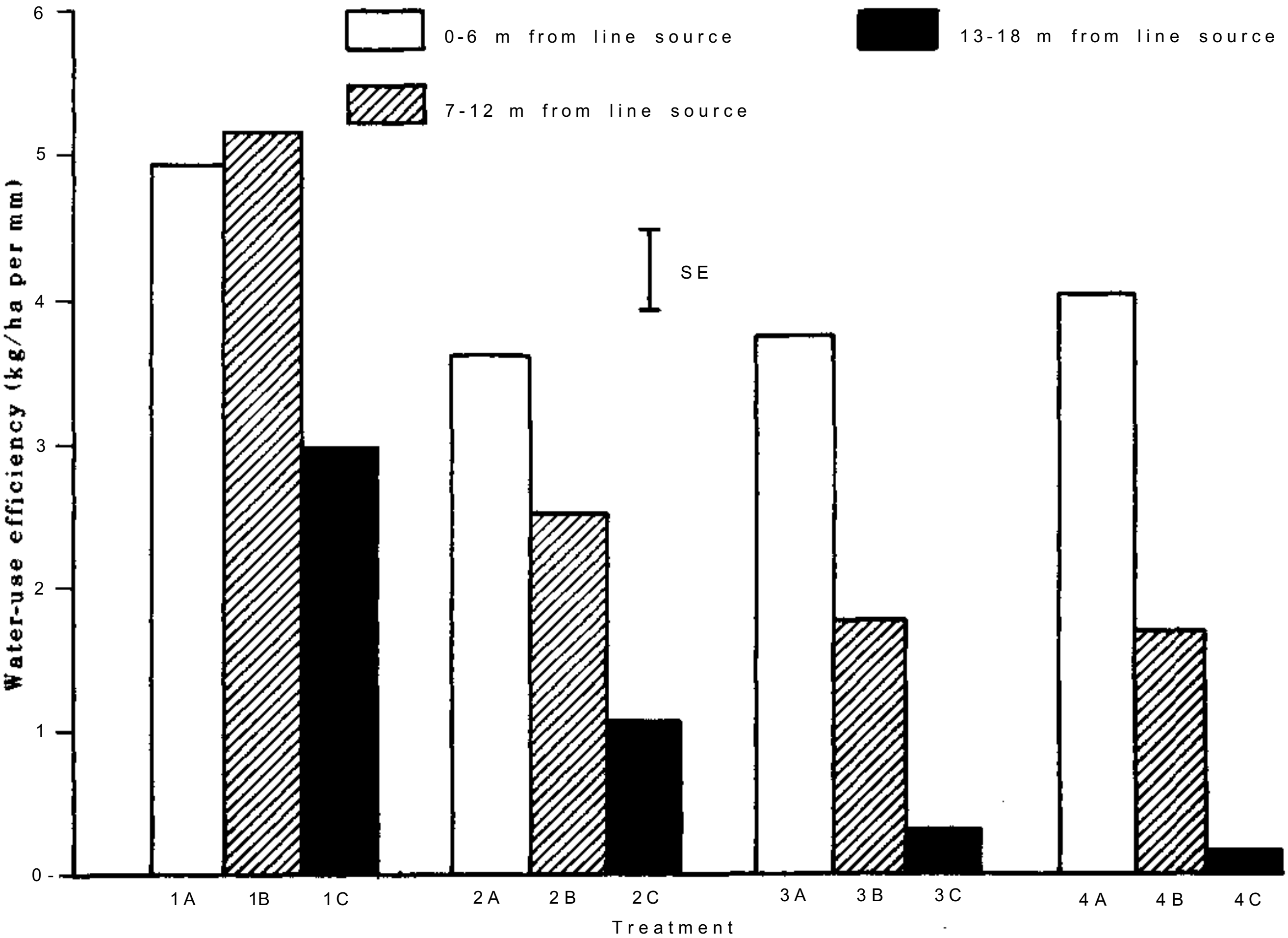


Figure 7. Effects of different drought stresses on water-use efficiency of groundnut (Robut 33-1), Alfisol, ICRISAT Center, 1981/82.

Table 8. Seed yield response (kg/ha) of two chickpea genotypes to irrigation[1] and dates of planting, ICRISAT Center, postrainy season 1981/82.

Planting date	Annigeri			L-550		
	I_0	I_1	I_2	I_0	I_1	I_2
20 Oct	1490	1960	2640	1230	1350	2300
4 Nov	1300	1640	2680	930	1300	2230
19 Nov	940	1360	2390	530	1470	1620
9 Dec	920	1120	1650	670	950	1120

1. For details of irrigation treatments, see Table 7 fn. 1.
SE for comparing irrigation x date x variety means, ±267.
SE for comparing date x variety at the same level of irrigation means, ±171.
SE for comparing varieties at the same level of irrigation x date means, ±135.
SE for comparing dates at the same level of irrigation x variety means, ±171.

By taking canopy and air temperatures daily at 1400 hr throughout the growing season, we monitored the SDD for Annigeri and L-550 in all treatments during the 1981/82 growing season. Figure 10 shows that water use by chickpea was linearly related to SDD.

Quantifying Drought Stress in Sorghum

To examine effects of drought stress at different phenological stages on leaf-area index, phenology, total dry matter, grain yield, and yield components, CSH-8-R and M 35-1 were sown 23 November 1981 on an Alfisol and a 4-cm irrigation was given the next day. Emergence was 28 November. Our two genotypes received these five moisture treatments: adequate moisture throughout growing season (M_0); stress during growth stage 1—(GS1) from emergence to panicle initiation, PI (M_1); stress during growth stage 2—from PI to anthesis (M_2); stress during growth stage 3—from anthesis to physiological maturity, PM (M_3); and stress during the latter part of both growth stages 2 and 3 (M_4).

Stress in GSl reduced the days to panicle initiation, while stress in GS2 delayed flowering—and maturity. Stress in GS3 reduced the grain-filling period (Table 9).

Treatment M_2 had a short grain-filling period and the lowest Leaf Area Index (LAI) almost throughout the growing season. Treatment M_3 caused a rapid reduction in LAI in GS3 and a shorter grain-filling period. Stress in GS3 (anthesis to PM) reduced total dry matter and grain yield the most for CSH-8-R (Table 9).

Grain yield and TDM for CSH-8-R (Fig.11) were highest in M_0 followed in order by M_1, M_4, M_2 and M_3. M35-1's grain yield and TDM were lower than CSH-8-R's under all treatments, but they responded similarly to drought stress.

Effects of Nitrogen and Drought Stress

In previous intercropping experiments with cereals, drought stress produced higher yield advantages than no-stress. During the 1982 summer season, we used 1 row sorghum:2 rows groundnut intercropped, compared with each crop alone—with sorghum getting either no nitrogen (N_0) or 100 kg N/ha (N_{100}). Moisture regimes imposed by line-source sprinkler were the same as described in previous years except that lower water pressure allowed four regimes this year instead of five. For the same reason, water discharged nearest the line did not keep the crop absolutely nonstressed. Still, the four moisture regimes represented four degrees of drought stress.

The grain yield of fertilized sorghum alone declined sharply with increased drought stress (Fig. 12), as did pod yield of groundnut alone. But the intercrop reductions were relatively low, so the total yield advantage from the intercrop ranged from 28% with the least drought stress to 148% with the most stress we applied—results similar to those previously reported.

Under N_0 treatment, with nitrogen stress severely limiting growth, sorghum alone did not respond to various drought stresses but it did with N_{100} treatment. Sorghum in intercrop

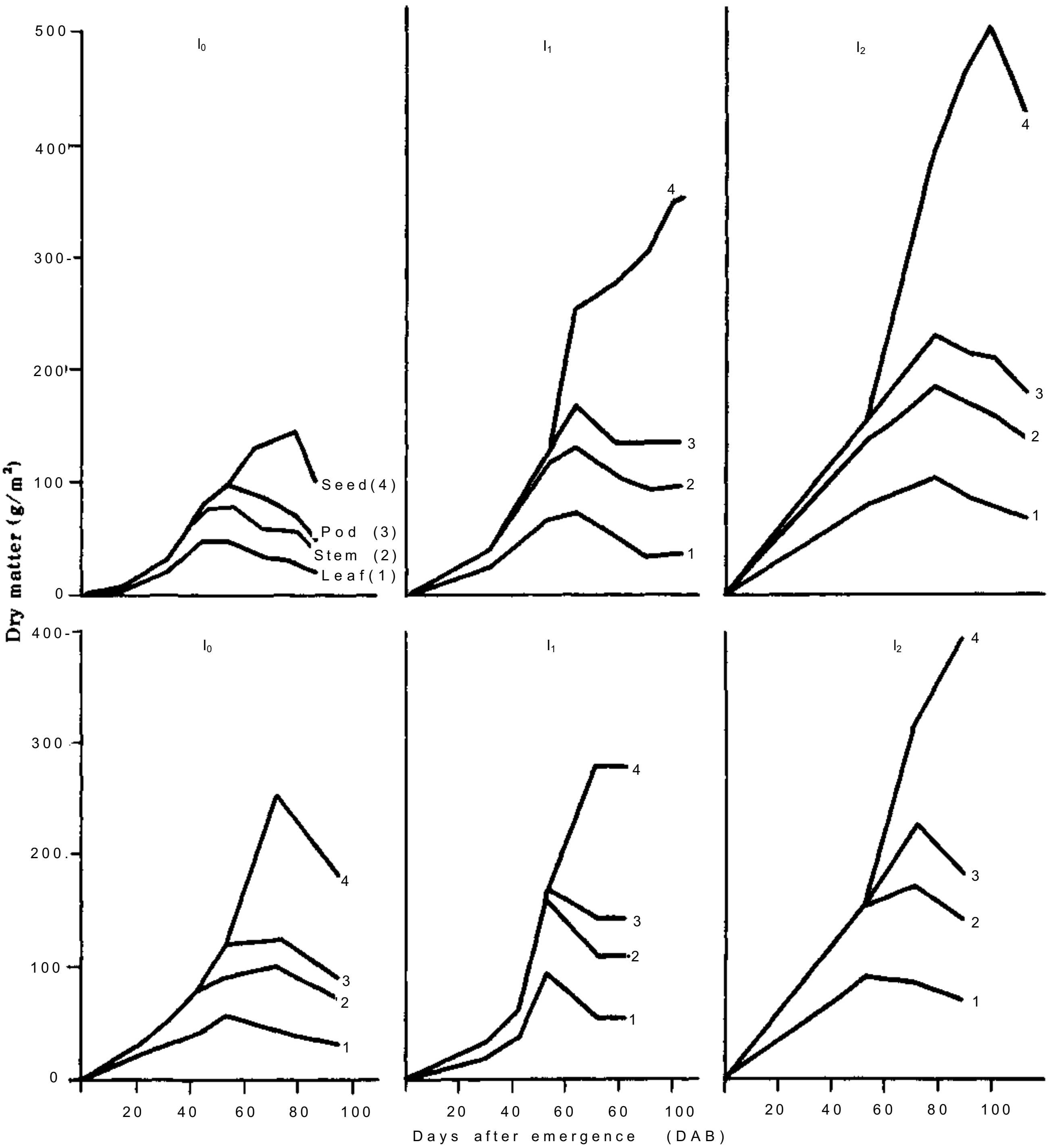


Figure 8. Dry-matter distribution in chickpea (Annigeri) grown under three irrigation regimes, planted 15 Oct 1980 (top) and 30 Nov 1980 (bottom). (I_0 = no irrigation; I_1 = two irrigations, 30 and 70 days after sowing; I_2 = four irrigations, 30, 50, 70, and 90 days after sowing).

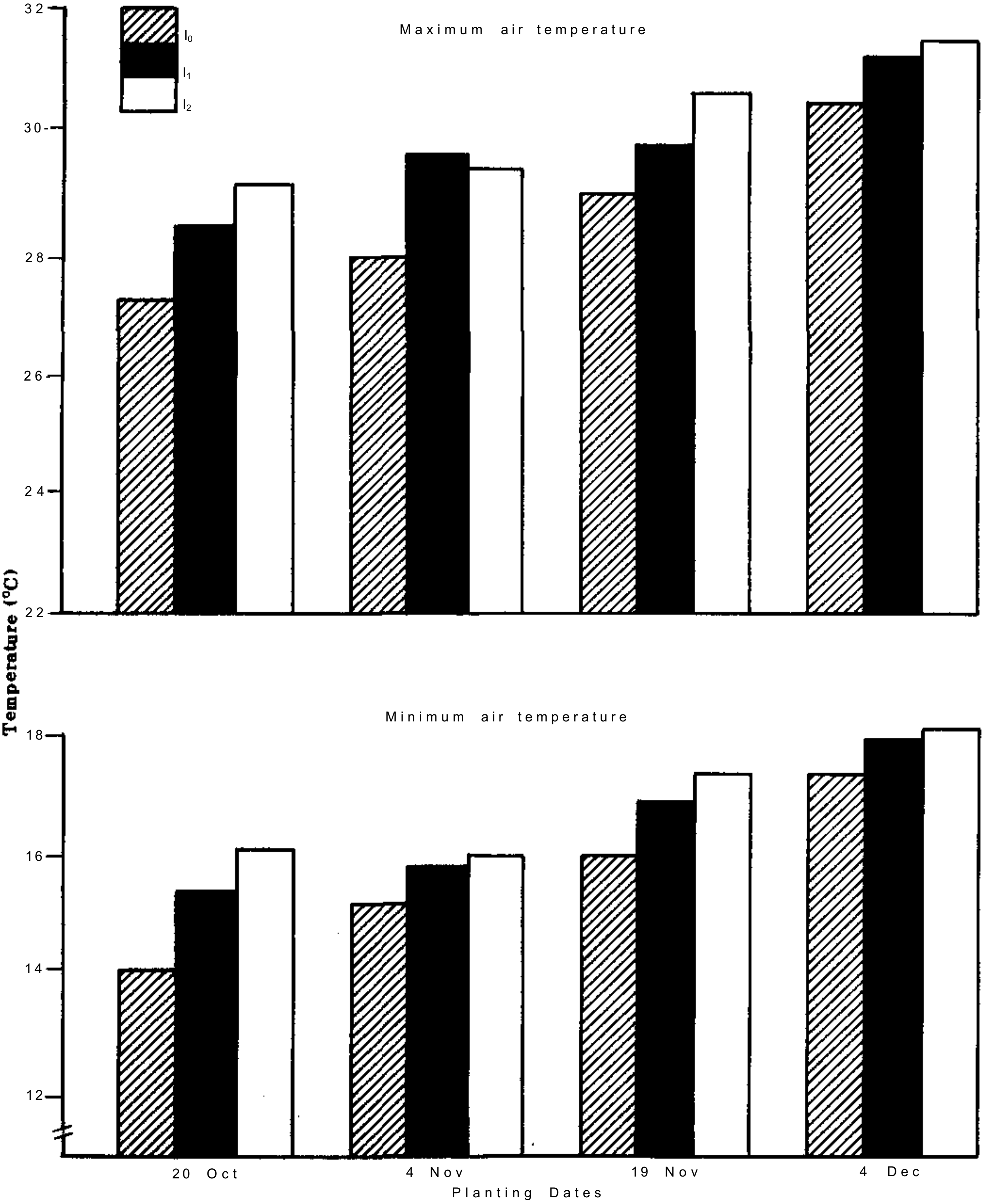


Figure 9. Average maximum and minimum air temperatures from 50% flowering to maturity of chickpea (Annigeri) sown on indicated dates, ICRISAT Center, 1981/82. (I_0 = no irrigation; I, = two irrigations, 30 and 70 days after sowing; I_2 = four irrigations, 30, 50, 70, and 90 days after sowing).

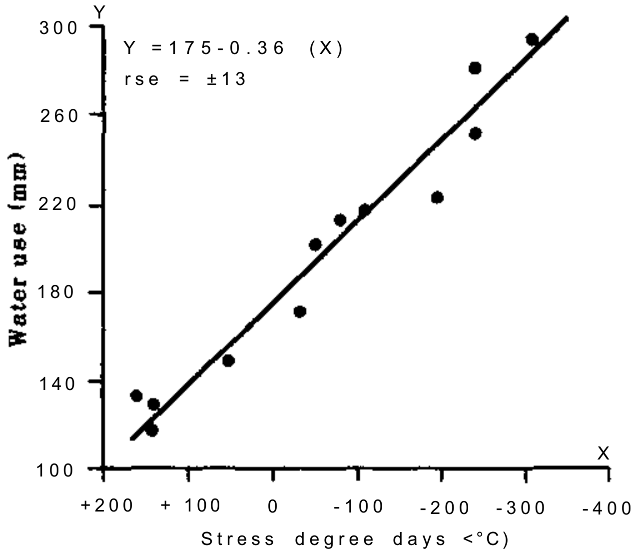


Figure 10. Relationship between stress degree days and water use of chickpea (Annigeri), ICRISAT Center, 1981/82.

responded similarly, so its intercrop yield did not respond to drought stress. But the relative yield of groundnut increased somewhat with increased stress (Fig. 13); total yield advantage from the intercrop ranged only from 31% under least stress to 39% under severe stress with nitrogen limiting.

Nutrients

That SAT soils are low in nutrients is well recognized, but little is known about how nutrients behave in SAT soils or how their behavior affects plant growth, so we are characterizing crop needs for nutrients, factors that influence crop needs, interactions between nutrients and the soil, and nutrients supplied by the soil. Major emphasis is given to nitrogen; we are increasing attention on phosphorus, and conducting long-term experiments studying nitrogen, phosphorus, and potassium.

Fate of Nitrogen Fertilizer on Alfisois

Agronomic results of the first 2 years of joint IFDC / ICRISAT field experiments were reported last year. The ^{15}N analyses of these 1980 and 1981 experiments provide additional information on the behavior of ^{15}N in two contrasting soils, Alfisois and Vertisols.

Rate of N application. In 1981, we examined recoveries of N in the sorghum crop and in the soil after harvest over the whole response curve for the Alfisol. Increasing N up to 120 kg/ha

Table 9. Phenology, grain yield (kg/ha) and total dry matter (kg/ha) of two sorghum genotypes under five moisture treatments imposed at different phenological stages, ICRISAT Center, postrainy season 1981/82.

Sorghum genotype	Moisture treatment	Growth stage [a] (DAE)			Grain yield	SE	TDM	SE
		PI	AN	PM				
CSH-8-R	M_0	23	66	106	5660	±113	12530	±518
	M_1	21	64	104	4550	±399	9620	±443
	M_2	23	68	108	3300	±54	6690	±288
	M_3	23	68	104	2910	±273	5810	±402
	M_4	23	68	106	3300	±327	6970	±361
M 35-1	M_0	27	72	112	3830	±181	10830	±1002
	M_1	25	68	no	3520	±122	8710	±2351
	M_2	27	72	110	1910	±59	6100	±153
	M_3	27	72	109	1980	±107	5250	±189
	M_4	27	72	108	2440	±211	6000	±389

a PI = panicle initiation; AN = anthesis; PM = physiological maturity.

b. Mo = Adequate moisture throughout the growing season; M_1 = stress at GS1; M_2 = stress at GS2; M3 = stress at GS3; M_4 = stress during later part of both GS2 and GS3.

increased grain yield and total N-uptake (Table 10); the equation for the response curve for grain yield (kg/ha) vs N applied (kg/ha) was y = 1616 + 54.9 N - 0.18 N2 ($R = 0.99^{**}$, rse = 187). Uptake of fertilizer-N, shown by ^{15}N analyses, increased until the applied-N reached 160 kg/ha, the highest rate. Percentages of N recovered in the plant were reasonably consistent (46 to 51%) overall rates applied but the percentage remaining in the

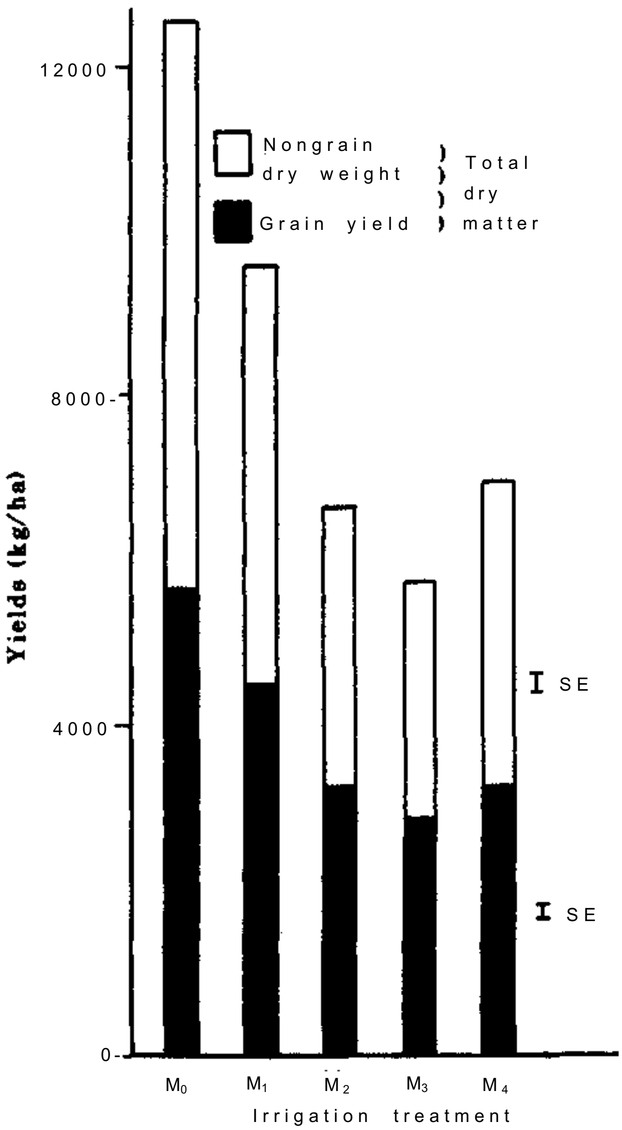


Figure 11. Effect of five irrigation treatments imposed at different phenological stages on sorghum (CSH-8-R) grain and total dry-matter yields on an Alfisol, ICRISAT Center, postrainy season 1981/82.

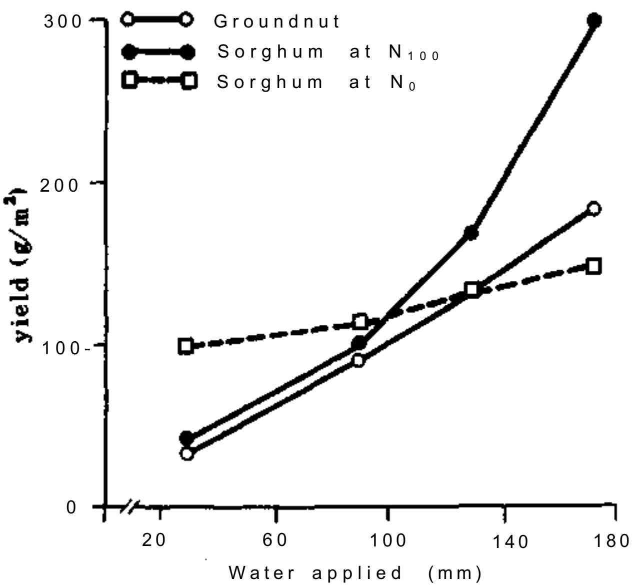


Figure 12. Effect of moisture regime on the grain yields of sole sorghum and pod yields of sole groundnut on an Alfisol, ICRISAT Center, 1982.

soil after harvest decreased with increasing applications (from 47% at 40 kg N/ha to 28% at 160 kg N/ha). As a result, total N recovered (in the plant and soil) decreased from 93%) at the lowest application rate to 79% at the highest.

Method of applying N fertilizer. The 1981 field experiment on an Alfisol also compared effects of different methods and times of applying N fertilizer on yield and recovery of nitrogen (Table 11). Putting the fertilizer into bands or spots (of super-granules) close to sorghum plants increased recovery of ^{15}N in the plant about 8%, significant at $P < 0.05$, but increases from split applications were not significant. Total recovery of ^{15}N in soil and plant for the different treatments ranged from 83 to 92%, but differences between treatments were not significant ($P < 0.05$).

Fate of Nitrogen Fertilizer on Vertisols

Compared with broadcasting at seeding, the 1981 combination of placing N fertilizer and split-application after crops emerged significantly increased yields ($P < 0.05$), total re-uptake ($P < 0.01$), uptake of ^{15}N ($P < 0.001$), and

Table 10. Grain yield, N uptake, and N recovery from indicated rates of urea-N applied to sorghum on an Alfisol, ICRISAT Center, rainy season 1981.

	N applied (kg/ha)					
	Check	40	80	120	160	SE
Gram yield (kg/ha)	1590	3650	4660	5720	5720	±320
N uptake (kg/ha)						
Total	31.9	61.9	83.6	111.4	116.3	±6.23
From fertilizer[1]		18.5	39.6	64.7	81.7	±1.76
From soil	31.9	43.4	44.0	46.7	34.6	
Recovery of fertilizer-N (%)						
Apparent (plant)[2]		75.0	64.6	66.2	52.7	±8.80
^{15}Nitrogen						
- in plant		46.3	49.5	53.9	51.1	±1.96
- in soil		46.9	33.7	31.1	27.8	±2.56
- plant + soil		93.2	82.2	85.0	78.9	±2.99
Residual fertilizer-N in soil (kg/ha)		18.8	27.0	37.3	44.5	

1. Calculated from ^{15}N content of plant.
2. From total N content of plant.

total recovery of ^{15}N from plant and soil (P< 0.01) (Table 12). The split-band treatment increased N uptake by the crop to 55% from about 30% (broadcast with or without incorporation). Total recovery of N (soil + crop) from 72 and 75% (broadcast) to 93% (split band) indicates that 28 and 25% of broadcast N were lost compared with only 7% lost when banded.

Efficient Use of Fertilizer

Using isotopically-labeled fertilizer-N is the most convenient and accurate way of assessing N fertilizer's fate. That method showed clearly—for the two soils over the two seasons—that uptake of N was satisfactory when the application methods used were those generally recommended; previous studies at ICRISAT reached a similar conclusion with the less accurate method of apparent recoveries (usually 50 to 70%), which the current ^{15}N experiments validated.

Previous results in India indicated that correct timing of N applications may be more important than placement, for most efficient use of

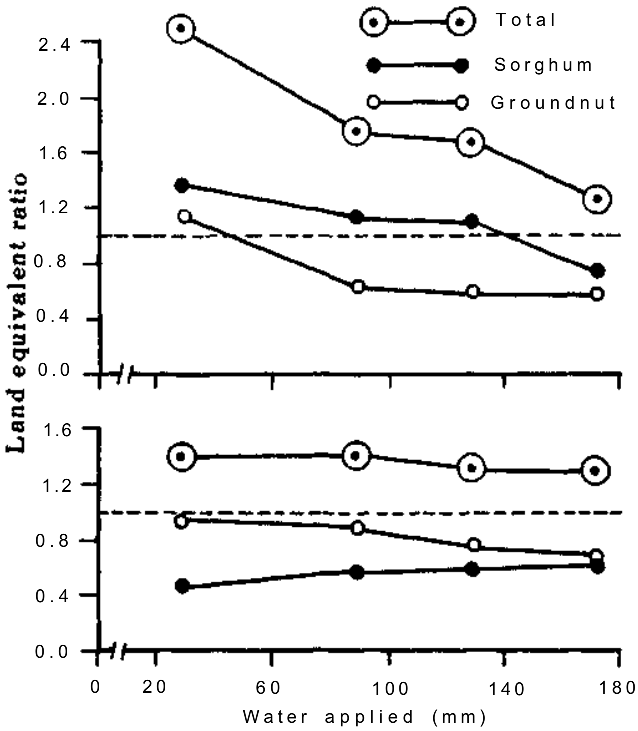


Figure 13. Effect of moisture regime on the relative yield advantages of sorghum/groundnut intercrop at N_{100} (top) and at N, (bottom) nitrogen levels, ICRISAT Center, 1982.

Table 11. Grain yield, N uptake, and N recovery for indicated methods of applying urea (80 kg N/ha) to sorghum on an Alfisol, ICRISAT Center, rainy season 1981.

	Surface broadcast	Broadcast, incorporated	Band, split	Band, all basal	USG[1] point	SE
Grain yield (kg/ha)	5450	4570	6040	5330	5190	±320
N uptake (kg/ha)						
Total	95.4	83.6	102.5	92.8	94.7	±6.23
From fertilizer[2]	40.7	39.6	50.0	45.9	46.8	±1.76
From soil	54.7	44.0	52.5	46.9	47.9	
Recovery of fertilizer-N (%)						
Apparent (plant)[3]	79.4	64.6	88.2	76.1	78.5	±8.80
^{15}Nitrogen						
- in plant	50.9	49.5	62.5	57.4	58.5	±1.96
- in soil	36.5	33.7	27.1	31.4	33.3	±2.56
- plant + soil	87.4	83.2	89.6	88.8	91.8	±2.99
Residual fertilizer-N in soil (kg/ha)	28.5	27.0	21.6	25.1	26.1	

1. USG = Urea super granule applied as 1 granule per two plants.
2. Calculated from ^{15}N content of plant.
3. From total N content of plant.

fertilizer-N by the plant. Timing the N application appears to have been the most important factor causing increased efficiency on the Vertisol in extremely wet 1981 rainy season. Appreciable losses of fertilizer from the Vertisol during 1981, but not in drier 1980, showed the need for further studies on interactions between fertilizer application methods and environmental conditions.

Mineralization of Soil Nitrogen

The need for nitrogen fertilizer is inversely related to the amounts of mineralized organic nitrogen (nitrate-N and ammonium-N) in the soil at seeding, and the amounts mineralized during the season. Few SAT soils mineralize enough nitrogen to meet cereal crops' needs, so added fertilizer N is generally needed. But mineralization patterns of different SAT soils have not been quantified. These patterns are necessary for developing future models to describe nutrient x soil x crop interactions in the SAT. So we examined the nitrate-N accumulations in two of the major soils at ICRISAT Center as part of a study of the effects of cultivation on soil properties.

Accumulations of nitrate-N in the two soils differed markedly; the Alfisol accumulated much more than the Vertisol over the latter part of the postrainy season and the first few weeks of the rainy season (Fig. 14). Greater accumulation in the Alfisol may result from less protection of soil organic matter from microbial attack because of the soil's lower clay content. To provide further information on that point, we estimated the amount of soil organic carbon in the soil biomass, which is the pool of living microorganisms in the soil.

With allowance for the differences in organic carbon contents of the two soils, the Alfisol contained 5 or 6 times as much biomass-C as the Vertisol (Table 13). Biomass-C was about 50% greater in the cultivated than in the uncultivated soil for a few weeks after cultivation and seeding, but the differences due to cultivation diminished within two months after seeding.

Table 12. Grain yield, N uptake, and N recovery for indicated methods of applying urea (72 kg N/ha) to sorghum on a Vertisol, ICRISAT Center, rainy season 1981.

	Surface broadcast	Broadcast incorporated	Split band	SE
Grain yield (kg/ha)	4260	4110	5220	±225
N uptake (kg/ha)				
Total	62.1	60.2	84.4	±3.84
From fertilizer[1]	22.3	21.3	39.6	±1.09
From soil	39.8	38.9	44.8	-
Recovery of fertilizer-N (%)				
Apparent (plant)[2]	31.8	30.0	61.9	±6.00
"Nitrogen				
- in plant	31.0	29.6	55.0	±1.55
- in soil	41.8	45.2	38.6	±2.69
- plant + soil	72.8	74.8	93.6	±2.41
Residual fertilizer-N in soil (kg/ha)	30.1	32.5	27.8	-

1. Calculated from ^{15}N content of plant.
2. From total N content of plant.

Nutrient x Soil x Environment Interactions: Urease Activity

The experiments on N efficiency examined effects of various application practices on crop yield and uptake of nitrogen, but more basic knowledge is required to characterize fertilizer x soil x environment interactions.

Urea is the dominant nitrogenous fertilizer used in the tropics; its usefulness depends on its hydrolysis to ammonium carbonate, which then decomposes to ammonium. The hydrolysis reaction is catalyzed by the enzyme urease. Most studies of urease activity in soils have been made on temperate soils with temperatures mainly up to 40°C. Effects of soil moisture contents on urease activity have received less attention. Both of those environmental variables are relevant to the farming system proposed for double cropping of Vertisols, because crops are dry seeded into a prepared seedbed just before the southwest monsoon; this harsh environment of high soil temperatures and dessicated soil may affect urease activity.

In laboratory experiments, the optimum temperature for maximum urease activity was 60^0 to 70^0c for both Alfisol and Vertisol. The temperature optima (Fig. 15) were similar at the soil pH and at pH 9 (usually the optimum pH for urease activity). A preliminary study showed clearly that urease activity increased with moisture content up to field capacity (24 and 40%, w/w, respectively, for the Alfisol and the Vertisol), but remained constant with further increases in moisture content (Fig. 16). Particularly dry soil sampled in May showed no urease

Table 13. Comparison of biomass-C contents of surface soil (0-15 cm) of an Alfisol and a Vertisol, ICRISAT Center, 1981.[a]

Measurement	Alfisol	Vertisol
Biomass (µg C/g soil)	11.4 ± 1.6	3.4 ± 0.3
Total C (%)	0.35	0.60
Biomass-C, (% of total C)	0.326	0.056

a. Sampling dates: Alfisol, 28 August; Vertisol, 25 August. Values are means from uncultivated and deep-cultivated plots.

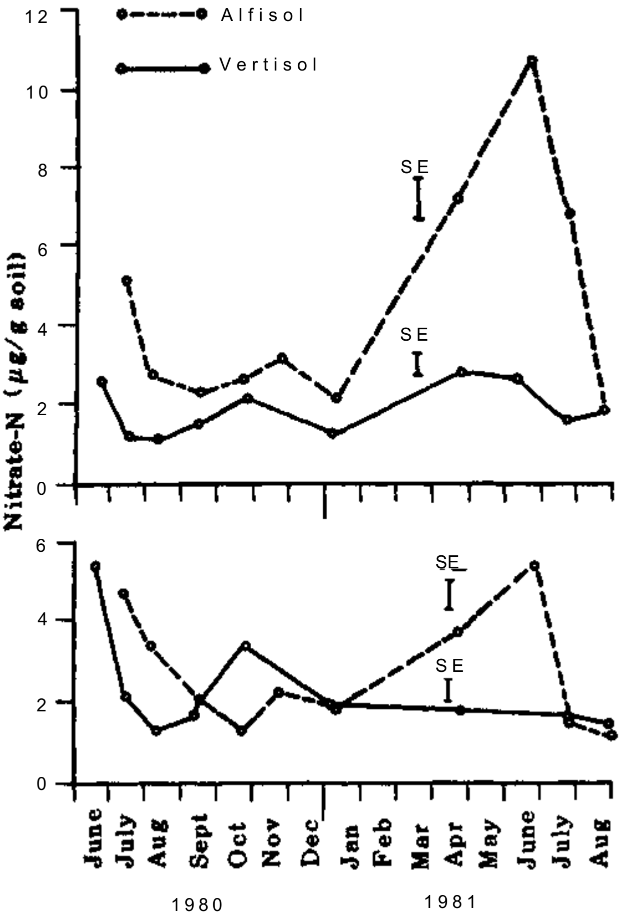


Figure 14. Seasonal fluctuations in the nitrate-N contents of surface 0-15 cm (top) and subsurface 15-30 cm (bottom) depths of an Alfisol and a Vertisol, ICRISAT Crater, 1980/81.

activity; moisture content was below the wilting point, being then in equilibrium in a relative humidity range of 20 to 40% (Table 14). Increasing the moisture content gradually by increasing humidity inside the incubation vessel to 100%, initiated slow mineralization of urea-N to ammonium. Losses of N from urea in dry soil, before the monsoon arrives, would be small or negligible.

Total N Analysis of Soil—Bal Modification

Studies of the behavior of nitrogen in soil commonly require an estimate of the total soil nitrogen content. An approximate value is sufficient for many generalizations. But nitrogen balance studies require high accuracy, so we re-evaluated one of the analytical procedures.

Total N content of soil usually is determined by the Kjeldahl method, which involves digesting soil with sulphuric acid and a mixture of salts to convert all the organic-N to ammonium-N. Because a small proportion of soil organic nitrogen may resist acid attack, the digestion procedures used vary widely. Some Indian soils (Vertisols) seem to require a further modification of the analytical procedure. The Bal modification, first proposed in 1926, involves soaking the soil sample in water a short period before commencing digestion. Our earlier routine evaluations indicated little need for the modification with the reduced-iron variation *of* the Kjeldahl method. But evaluations were needed for the salicylic acid variation of the Kjeldahl method, which is used in the 1FDC/ ICRISAT project. This study was an integral part of that project.

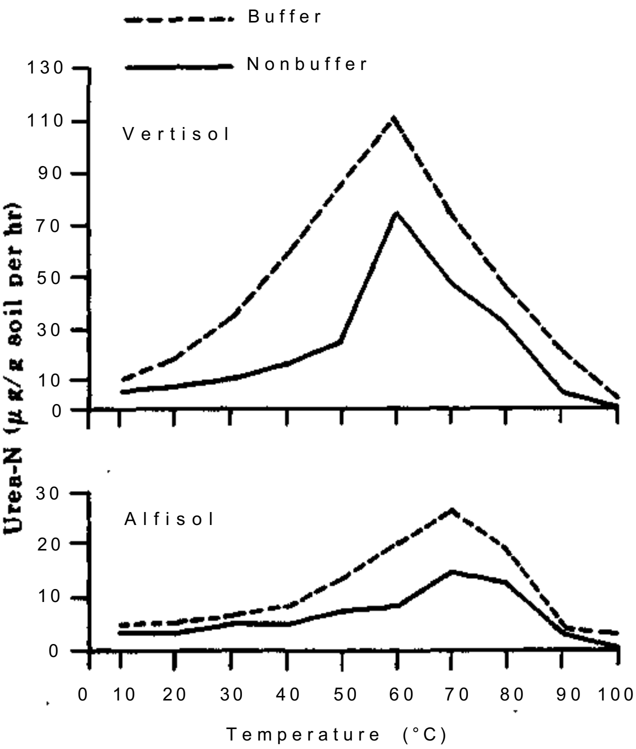


Figure 15. Effect of temperature on soil urease activity, in a Vertisol (top) and an Alfisol (bottom). (Standard error for comparisons at the same level of temperature of method = 1.9 µg N/g per hr).

Table 14. Urea hydrolosis in air-dried soil samples as influenced by humidity of the incubation environment.[1]

Soil	Incubation environment	Urea hydrolyzed (µg/g soil) after days 1	2	4	5	7
Alfisol	Dry[2]	0	0	0	0	0
	Humid	0	36	44	129	164
Vertisol	Dry[2]	0	0	0	0	0
	Humid	0	27	44	84	119

1. Soil samples (5 g) were treated with 1000 µg urea N/g soil in solid form and incubated at 37°C.
2. Relative humidity in the dry and humid environments were, respectively, 20-30% and 100%.

The evaluations showed strong interactions between the Bal modification (soaking before digestion), fineness of soil grinding, and the duration of digestion (Table 15). The Bal modification markedly improved recovery of nitrogen, particularly from coarse-ground samples digested for a minimum time (2 hr). But the increases resulting from using the modification were much less from finely ground samples digested for 5 hr—the usual analytical conditions used by research scientists.

Further studies examined variations in the Bal effect with depth in a Vertisol profile (Table 16). The decrease in Bal effect with depth, and the associated decrease in organic nitrogen with no change in non-exchangeable ammonium, provided good presumptive evidence that the effect was related to improved recovery of soil organic nitrogen and not of non-exchangeable ammonium. The effect did not appear to be important in any horizon of an Alfisol (Table 17).

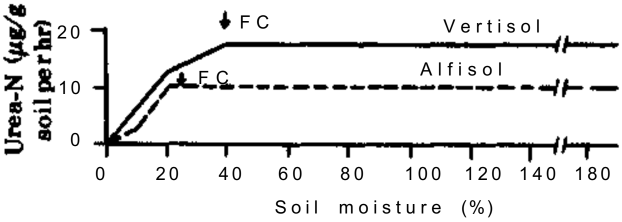


Figure 16. Effect of moisture content on soil urease activity at 37°C. Field capacity (FC) of each soil indicated by an arrow.

Nutrient Requirements of ICRISAT Soils

Although experiments during the first few years at ICRISAT Center established the general fertilizer requirements of crops, characterization of the nutrient requirements of various soil-crop combinations has been limited. Further studies on the requirements of various soils and improved farming systems practices are being undertaken.

Response of Crops on Vertisols to Applied Phosphorus

When the soils at ICRISAT Center were cropped to improved cultivars for the first time,

Table 15. Effect of water pretreatment ('Bal modification'), fineness of grinding, and digestion time on the estimated total-N content (µg N/g soil) of surface horizon of Vertisol, measured by semi-micro Kjeldahl method (salicylic acid modification).

Soil particle size (mm)	Digestion time (hr)	Total N content, Bal modification: Without	With	Increase due to Bal pretreatment (%)
<0.8	2	421 ± 4	570 ± 3	35
<0.8	5	486 ± 10	571 ± 6	17
<0.16	2	561 ± 2	595 ± 0	6
<0.16	5	584 ± 0	595 ± 0	1

Table 16. Variation in the Bal effect and other soil properties with depth in a Vertisol profile.

Soil depth (cm)	Ammonium + nitrate-N	Fixed NH4-N	Organic N[2]	Total N content[1] Bal pretreatment Without (a)	With (b)	Bal effect b-a
	μg N/g soil					
0 - 15	3	113	371	390	487	97
15- 30	3	107	278	303	388	85
30 - 60	3	100	231	255	334	79
60- 90	3	99	205	236	307	71
90-120	4	110	208	252	322	70
120-150	4	102	174	210	280	70
150-170	3	100	145	197	248	51

1. Total N determined as 1-g samples of soil ground to pass a sieve with 0.8-mm openings.
2. Organic N = Total N (b) - (NH_4- + NO_3-N) - fixed NH4-N.

they required added phosphorus. Without it foliar symptoms of phosphorus deficiency developed. After a phosphatic fertilizer has been applied several years, foliar symptoms of phosphorus deficiency no longer appear in crops. But the level of available-P (as measured by the Olsen method) is still low in many Vertisols, so we examined responses to applied P by sorghum grown in ICRISAT Center's watersheds on Vertisols.

The preliminary experiments (Table 18) showed that Vertisols did not respond appreciably to applied P, even when Olsen's 0.5 *M* sodium bicarbonate test showed available-P is less than 2 ppm, which is usually considered to indicate highly deficient soil. Results from the long-term phosphorus experiment on an Alfisol indicate that Alfisols differ from Vertisols in their soil test-crop response relationships, at least with respect to phosphorus; sorghum crops on the Alfisol responded much more to added phosphorus than sorghum on the Vertisols, even though initial available-P was higher in the Alfisol (Table 18).

Further studies are comparing the differences in the behavior of P in Vertisols and Alfisols, and its availability to crops.

Long-term Phosphorus Experiment

This experiment is providing information on the responsiveness of a 2-year rotation of sole sorghum and a millet/pigeonpea intercrop to water-soluble phosphorus, and the extent that

Table 17. Effect of the Bal pretreatment of samples on estimates of the total-N content (*μg* N/g soil) of horizons of an Alfisol profile.

Soil horizon	Soil depth (cm)	Clay (%)	Total N estimate Bal modification Without	With
Ap	0- 10	19	561 ±10	549 ±15
B1	10- 20	30	647 ± 2	642 ±18
B21t	20- 49	41	823 ± 7	847 ± 6
B22t	49-102	41	482 ± 7	498 ±18

Table 18. Response of rainy-season sorghum to phosphorus on Vertisols and an Alfisol.

Experiment	Year	Soil available P[1] (ppm)	Fertilizer-P applied (kg/ha)	Grain yield (kg/ha)		SE	Response to P (%)
				Without P	With P		
Vertisol							
N x P x S	1981	1.0	40	1880	2490	±72	33
Date planted[2]	1981	1.4	20	1980	2350	±19	19
N x P	1981	1.5	40	4380	4670	±95	7
Alfisol							
Long-term	1976-79	3.1	20	1310	2800	±111	113

1. Olsen method (0.5 *M* $NaHCO_3$).
2. Results are the mean of the two planting dates in the rainy season.

rock phosphate can substitute for water-soluble phosphorus.

Responses this year agreed with those in previous years; relative responses to added phosphorus were sorghum> millet» pigeonpea. Responses to water-soluble P, and to rock phosphate, were greater than in previous years. But rock phosphate remained much less effective than water-soluble phosphorus. Two control treatments were added this year to determine whether sulphur is needed, especially where the P source (rock phosphate) contains little or no sulphur. There was no significant sulphur requirement.

Long-term Potassium Experiment

The low clay content of many Alfisols in India and the substantial amounts of kaolinite in the soils' clay-size particles have been the basis for the commonly held view that potassium may be rapidly depleted in Alfisols by intensive cropping. A long-term experiment was started in 1979 to examine soil potassium's depletion rate and the relationship of the depletion to the onset of potassium deficiency in an Alfisol intensively cropped at ICRISAT Center.

Potassium deficiency could not be detected in a site-conditioning crop in 1978 nor in the 1979 experiment. But some indications of marginal potassium deficiency appeared in 1980. Yield responses to added potassium in 1981 were consistent in some components of the cropping systems (Tables. 19 and 20). Straw yields of both sorghum and millet increased significantly ($P < 0.05$) with added potassium (Fig. 17); the straw yields include stalks and leaves, but not the head-chaff. After the 4th year (1982) of this experiment, the soils will be resampled to determine the depletion of soil potassium.

Nitrogen Balances in Cropping Systems

Although recent research has identified several improved cropping systems, their fertilizer requirements still are not well understood. Investigations of nutrient requirements have been confined mainly to annual experiments. Long-term nutrient requirements of the various cropping systems, and the effects of the system on soil fertility, have received little attention. To remedy that, we started an experiment with sorghum and pigeonpea grown alone, rotationally, and intercropped on an Alfisol with several rates of nitrogen fertilizer applied to sorghum so yield responses would complement separate measurements of changes in soil nitrogen contents. This experiment is on low-fertility soil in the pesticide-free area of the Center. A droughty spell and shoot fly attack caused low and variable yields in the first year (1981).

Nitrogen on a Millet/Groundnut Intercrop

Last year we reported that millet grown in the

Table 19. Grain yields in a long-term potassium experiment on an Alfisol, ICRISAT Center, 1981.

Treatment N (kg/ha)	Treatment K (kg/ha)	Other[1]	Grain yield (kg/ha) Sorghum	Pigeonpea	Millet	Groundnut
0	0		2770	900	840	850
60	0		3930	960	1200	780
120	0		4010	900	1540	840
120	0	FI	4550	1010	1220	700
120	0	FYM	4800	1140	1790	630
0	0	FYM	3290	1430	1120	900
120	30		4560	1180	1520	890
120	60		4660	1060	1570	800
120	120		5000	1060	1690	920
SE			±196	± 91	±100	±93
CV(%)			8.1	14.6	12.4	19.8

1. FI = fodder (cereal) incorporated; FYM = farmyard manure.

millet/groundnut intercrop (1:2 and 1:3 row arrangements) responded less to nitrogen fertilizer than when grown as a sole crop—owing to both the wide distance between millet rows (90 to 120 cm) and to the groundnut intercrop. How much groundnut and millet compete for fertilizer applied to the millet is not known, so we conducted experiments with nitrogen in which this fertilizer was labeled with ^{15}N. The ^{15}N analyses are now complete.

The results showed that the groundnut row closest to the millet only 30 cm away did not

Table 20. Straw yields in a long-term potassium experiment on an Alfisol, ICRISAT Center, 1981.

Treatment N (kg/ha)	Treatment K (kg/ha)	Other[1]	Straws yield (kg/ha) Sorghum	Pigeonpea	Millet	Groundnut
0	0		2520	1060	1090	990
60	0		2960	1060	1510	980
120	0		3110	1100	1630	1020
120	0	FI	3280	1480	1930	790
120	0	FYM	1780	2380	2380	860
0	0	FYM	2940	2000	1700	970
120	30		3500	1600	1850	840
120	60		3530	1460	2000	940
120	120		4210	1470	2150	990
SE			±181	±141	±159	±83
CV(%)			9.0	16.8	15.3	15.4

1. FI = fodder (cereal) incorporated; FYM = farmyard manure.
2. Straw = Stalk + leaves.

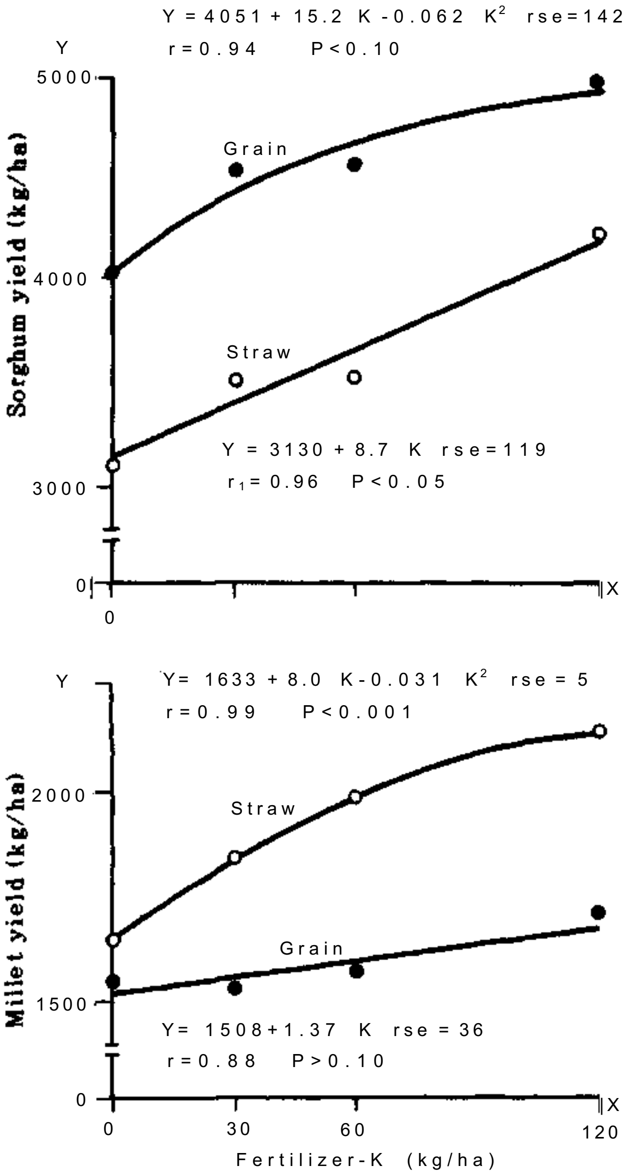


Figure 17. Response of sorghum and millet to fertilizer-K, long-term potassium experiment, Alfisol, ICRISAT Center, 1981.

compete substantially with millet for N applied as a band to the millet (Table 21); the ^{15}N content indicates that the closest groundnut row obtained less than 0.5% of its nitrogen from the adjacent band of fertilizer. But "intercropped" millet absorbed substantial nitrogen from fertilizer applied to an adjacent row (upto 30% of that absorbed by the treated row). The intercropped millet, fertilized with unlabeled fertilizer-N, grew in the same row position as groundnut. These results clearly demonstrate that millet's roots have much greater foraging ability than groundnut's.

Concentration of ^{15}N in millet straw was higher with the groundnut intercrop present than absent (Table 22); uptake of unlabeled mineral nitrogen by the groundnut from the soil between rows of the millet intercrop appears to have been the major cause.

Apparently the groundnut intercrop does not compete with millet for N applied to the millet, but it does compete for the mineralized-N in the soil between millet rows. The importance of such competition for millet growth will require further studies to assess simultaneously the effects of competition for water and nutrients.

On-station Component Research

Tillage

It is possible to obtain a seedbed of desired quality by various tillage operations. Since soil physical properties and moisture requirements of crops are not fully understood, we must evaluate various tillage methods for different soil types and agroclimatic conditions.

India's light-textured Alfisols are generally shallow with limited water-holding capacity. They become so hard when dry that rain, rather than the proper agronomic time, often dictates tillage operations. The soils are structurally weak and often develop surface crusts that reduce infiltration and thus increase runoff and soil erosion. The soil crusts also restrict seedling emergence.

An experiment was conducted in an Alfisol field in a split-plot design with four replications. Primary tillage methods on beds were the main plots and the soil-covering and seed-compaction devices, the subplots. Details of the treatments follow:

Primary tillage treatments:

1. Bed splitting followed by two strip plowings with right and left hand moldboard plows.

Table 21. Enrichment in ^{15}N (% stoma excess x 10^{-3}) of rows of millet/groundnut intercrops due to uptake of fertilizer-^{15}N applied to a single row of millet, ICRISAT Center, rainy season 1981.

	Intercropped area[1]			^{15}N-fertilized	Intercropped area[1]		
Intercrop	S_3	S_2	S_1	row (millet)	N_1	N_2	N_3
Millet	4	18	148	916	471	32	8
	±4.1	±3.1	±40.1	±131.4	±77.8	±5	±6.1
Groundnut	4	7	18	911	39	5	5
(1:3)	±0.6	±2.3	±2.3	±156.9	±8.3	±0.3	±0.3
Groundnut		9	24	1070	37	3	
(1:2)		±1.2	±5.4	±205.8	±7.1	±1.0	

1. S_1-S_3 and N_1-N_3 refer to rows (1st, 2nd, or 3rd) south (S) or north (N) of the ^{15}N-fertilized millet row. Fertilizer was applied in a band 5 cm from the north side of the millet row and S cm deep.

2. Strip plowing outer edges of the bed with right and left hand moldboard plows.
3. Chiseling future crop rows followed by blade harrowing.
4. Shallow tillage with duck-foot shovels.
5. Bed splitting followed by two strip plowings with right and left hand disc plows.
6. Strip plowing outer edges of the bed with right and left hand disc plows.

Table 22. Effect of a groundnut intercrop on the ^{15}N-enrkhment (% atoms excess x 10^{-3}) of millet fertilized with 40 kg/ha of ^{15}N-enriched fertilizer-N (4.9% atoms excess), ICRISAT Center, rainy season 1981.

	Millet interrow spacing[2]		
Intercrop[1]	90 cm	120 cm	Means
	^{15}N enrichment (atoms % excess x 10^{-3})		
Millet	581	501	541
Groundnut	716	689	702
SE	±49.5		±35.0

1. Interrow spacing of 30 cm.
2. Equivalent to the spacings for 1:2 and 1:3 millet/groundnut intercrop system.

The after-planting, soil-covering, and compaction-device subtreatments consisted of:

1. Band wheels compacting the soil surface.
2. Finger-type, soil-covering device covering the furrows with loose soil and small clods.
3. Narrow wheels compacting the soil at seed level, followed by a finger-type, soil-covering device.

The pull required by the tillage operation was measured for 10 m with a mechanical pull meter. Depths of cut ranged from 7 to 15 cm, and the draft varied from 150 to 200 kg. Where the depth of cut was only 4 cm, the draft was only 100 kg.

Regardless of type of tillage, soon after it was imposed bulk densities of the surface soil (0 to 15 cm) did not differ significantly.

Soil moisture was monitored from millet's emergence to its three-leaf stage. Depletion of soil moisture from the top 20 cm during 9 dry days is shown in Figure 18. Soil moisture in all the treatments was at field capacity at the beginning of the period. After 9 days without rain, mpisture levels differed significantly. The deep-tilled soil held more water at field capacity than the shallow-tilled, but lost more moisture than the shallow-tilled soil during the dry period, so less moisture remained in the deep-tilled than in shallow-tilled soil.

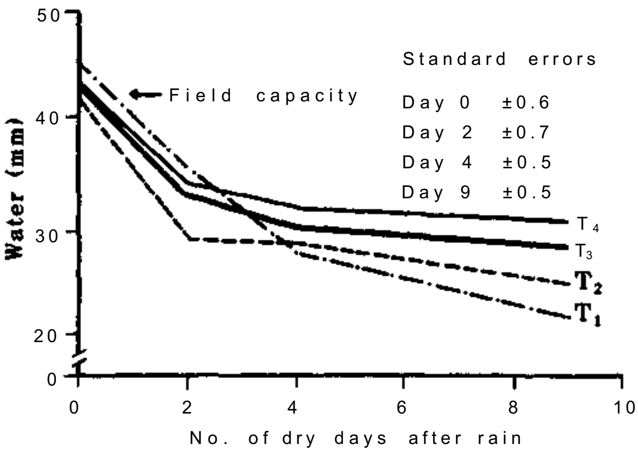


Figure 18. Moisture loss from top 20-cm plow layer of soil during a rainless period, ICRISAT Center, 1981. (T_1 = bed splitting and strip plowing; T_2 = strip plowing; T_3 = chiseling; T_4 = shallow tillage).

We have two hypotheses to explain the differences in soil moisture contents. First, the deep-tilled soil provided a conducive soil environment for better root growth, which leads to higher transpiration rates and faster moisture depletion. Second, in shallow tillage the soil in the plow layer was stratified in two layers, a top tilled layer and an unfilled lower layer. The resulting discontinuity of pores may have increased resistance to moisture migration so the top layer, after drying, acted as a mulch that prevented evaporation from the lower layer. The bulk density data indicate higher porosity in the deep-plowed soil, which would aid evaporation. Both hypotheses need to be investigated.

Cultivation and Soil Nitrogen

Results presented last year showed that increasing the depth of cultivation caused modest increases in sorghum yields and nitrogen uptake from both an Alfisol and a Vertisol. But cultivation depth had no significant effects on nitrate-N accumulated during the rainy season; therefore, the modest crop responses to deep cultivation may have resulted from cultivation affecting physical properties of the surface soils. So we investigated that possibility by different experiments on each soil.

Effect of cultivation on response to fertilizer-N. The response curves relating sorghum grain yield to applied fertilizer-N were determined for a deep cultivated (12 to 15 cm) and uncultivated deep Vertisol in 1981. The differences in yields between treatments increased with increased nitrogen, which indicates that the yield increases due to cultivation resulted from factors other than cultivation's effect on mineralization of soil nitrogen (Fig. 19). Thus, the results show that maximum response to added nitrogen will be achieved only if the soil is cultivated reasonably deep.

Straw: DC $Y = 4220 + 112.8\,N - 0.381\,N^2$
rse = 367 $R = 0.99$ $P < 0.01$
ZC $Y = 3390 + 104.1\,N - 0.351\,N^2$
rse = 235 $R = 0.99$ $P < 0.01$

Grain: DC $Y = 810 + 47.4\,N - 0.139\,N^2$
rse = 187 $R = 0.99$ $P < 0.01$
ZC $Y = 870 + 25.9\,N - 0.027\,N^2$
rse = 223 $R = 0.95$ $P < 0.01$

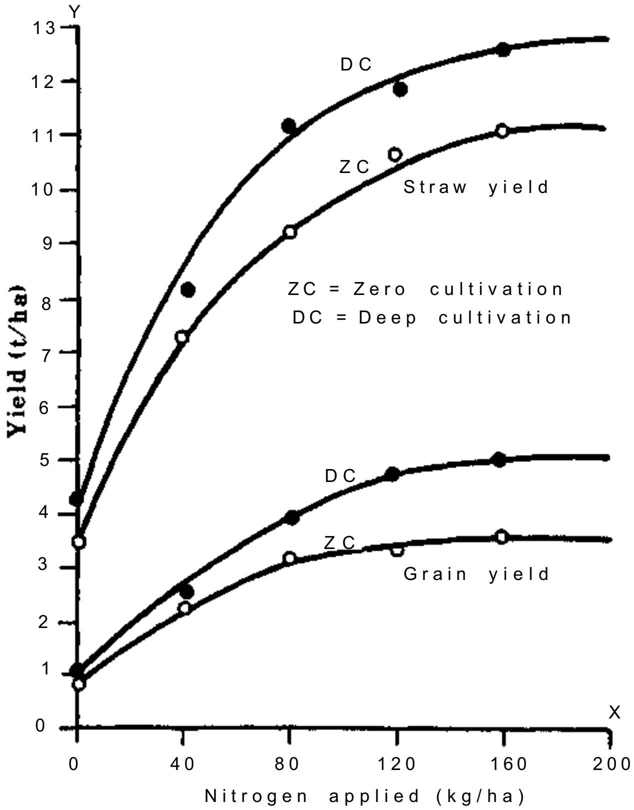


Figure 19. Effect of cultivation on response to nitrogen of a rainy-season sorghum on a Vertisol, ICRISAT Center, 1981.

Surface structure of Alfisols. With no cultivation, the surface soil of Alfisols compacts and a surface crust forms readily, often after a single shower. The crust markedly reduces infiltration, so frequent shallow cultivations practiced by some farmers after almost every rain on these soils not only removes weeds but also restores infiltration capacity. To investigate the consequences for soil nitrogen availability from minimizing the development of surface crusts, we stabilized the soil's surface with a synthetic stabilizer, polyvinyl alcohol (PVA).

PVA reduced runoff from 46 to 6%, and thus increased infiltration from 54 to 94% (Table 23). Preventing a surface crust from forming thus improved rain infiltration for crop productivity, but the additional infiltration leached nitrate-nitrogen deeper into the soil, as shown in Figure 20.

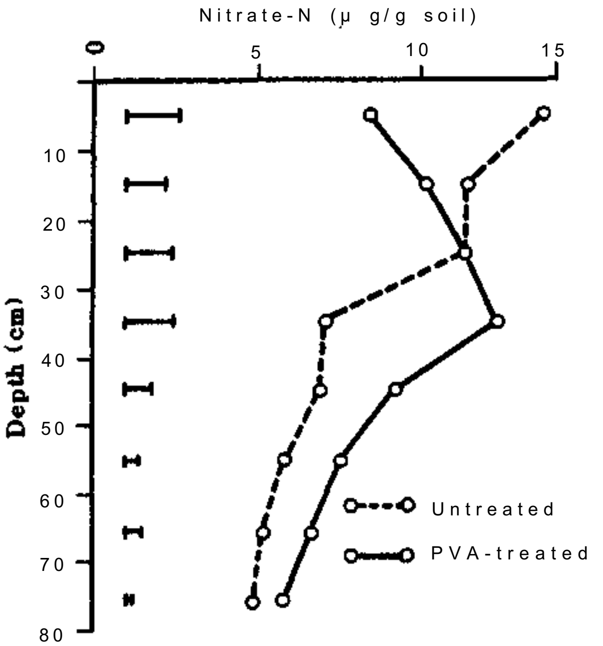


Figure 20. Movement of nitrate-N in nontreated and PVA-treated Alfisol, under natural rainfall, ICRISAT Center, 1982.

Effect of Different Tillage Systems on *Cynodon dactylon*

We initiated a long-term tillage experiment this year on effective management of *Cynodon dactylon* L. in medium-to-deep Vertisols where it is a serious perennial weed. The different tillage treatments include:

1. Conventional strip tillage: plowing a 20- to 25-cm strip on the edge of each bed of 1 m width, depositing the loose soil on the center of the bed, clearing the furrows with a ridger and cultivating broadbeds and furrows.

2. Complete tillage on beds: making a furrow

Table 23. Influence of Polyvinyl alcohol (PVA) on rainfall runoff on an Alfisol, ICRISAT Center, 1981.

		Runoff							
		Amount (mm)				Percent of rainfall			
		PVA treated		Untreated		PVA treated		Untreated	
Date	Rainfall (mm)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
18 Aug	13.6	0	0	3.8	2.8	0	0	28	21
30 Aug	44.5	3.1	2.5	19.0	16.3	7	6	43	37
2 Sept	11.4	0.5	0	4.6	3.9	4	0	40	34
3 Sept	22.0	4.0	2.2	16.4	17.0	18	10	45	77
Total	91.5	7.6	4.7	43.8	40.0				
Mean						7.9	4.4	47.9	43.8
Treatment means		6.2		41.9		6.2		45.9	

in the center of the bed followed by two passes of right and left hand plows.

3. Deep plow and rebuild beds: plowing on beds, bedridging, and bed forming.

4. Traditional system: monsoon fallowing, flat cultivation with local implements, and growing postrainy-season sorghum on conserved soil moisture.

5. No-crop, no-tillage was included to study *Cynodon* behavior in an undisturbed field and as a control.

In the first three treatments, a sorghum/pigeonpea intercrop was sown before the June monsoon. The fourth treatment (traditional crop) was sown in October, after the rainy season. All four treatments received one mechanical intercultivation, then one hand weeding.

The first year, increased tillage markedly decreased total weed dry matter at sorghum harvest. *Cynodon* dry matter in the first three rainy season cropping treatments was always less than 20% of the *Cynodon* dry matter in the control. Though there was minimum *Cynodon* in the postrainy cropping treatment, the weed dry matter in the no-crop, no-tillage system was similar to that before the experiment started in dry season, so the traditional system of postrainy season cropping does not help minimize *Cynodon* infestation but manages it efficiently by repeated tillage (harrowing) during dry spells in the rainy season.

The same treatments are being monitored further to observe long-term effects of tillage treatment on *Cynodon dactylon* in the deep Vertisols.

Soil Crusting and Tillage

The effectiveness of shallow tillage to break the crust and improve infiltration and soil moisture conservation was studied in an experiment on 10- x 5-m plots on a bare Alfisol. The treatments were:

1. Flat configuration with shallow tillage after every major storm.
2. Flat configuration with no tillage during the rainy season.
3. Broadbed-and-furrow (BBF) configuration with shallow tillage after every major storm.
4. BBF configuration with no tillage during the rainy season.

Each treatment was replicated and runoff, soil loss, and soil moisture were measured.

Rainfall in 1981 produced little crusting or hardening of topsoil. Observations on crusting will continue. In the entire season, treatments 1 and 3 received only five shallow tillage operations. Monitoring of runoff and soil loss was not started until 10 August. The results (Table 24) indicate that shallow tillage effectively reduced runoff in both flat and BBF surface configurations, but it significantly reduced soil loss only from the BBF configuration.

Small-scale Land Management

Experiments aimed at developing improved land-management systems for Alfisols have been conducted at ICRISAT Center since 1974. We have concentrated on different land configurations—flat-on-grade, broadbed-and-furrow, and narrow-ridge systems, which we evaluated in 0.3- to 0.4-ha field plots. The results have not been conclusive. Thus the need to better

Table 24. Effects of shallow tillage and land-shaping on runoff and soil loss from an uncropped Alfisol, ICRISAT Center, 1981.

Tillage system			
Depth	Land shaping	Runoff *(mm)*	Soil loss (t/ha)
Shallow	Flat	138	3.2
	BBF	168	5.9
Nil	Flat	214	3.6
	BBF	289	8.9
SE		±8.2	±0.57

BBF = Broadbed and furrow.

understand specific problems associated with land management on Alfisols prompted us to initiate experiments on small plots in 1979/80 to obtain better qualitative and quantitative understanding of how some factors influence runoff and erosion on Alfisols, and to help us develop more effective land management systems that conserve soil and water resources.

Organic Mulch Experiment

This experiment was initiated to determine effects on runoff, soil loss, and crop yield from different mulches—0, 2.5, 5, and 10 tonne/ha of groundnut shells. Eight small plots (10 x 5 m), were used, and each plot was provided with a multislot divisor system to measure runoff up to about 120 mm per storm. Two neutron access tubes in each plot helped monitor soil moisture; soil temperature was observed twice daily at three soil depths: 5, 15, and 30 cm. Each intercrop plot of sorghum and pigeonpea was replicated twice; a flat cultivation system was used.

The organic mulch was applied 7 July so runoff and soil losses are reported only after that. All organic mulch treatments effectively reduced runoff and soil loss. The 10 000 kg/ha rate reduced runoff 74% and soil loss 80% and increased sorghum yield 9% and pigeonpea yield 35%. The 2500 kg/ha mulch did not affect sorghum or pigeonpea yields.

Runoff, soil losses, and crop yields in 1981 are shown in Table 25. All the mulch treatments effectively reduced runoff and soil loss from storms of less than 20mm. Heavier mulch rates were more effective with storms 20 to 50 mm. The heaviest mulch treatment we used was much less effective with storms of 50 mm and more.

Deciding Length in the BBF

A crucial point in laying out the BBF system is the maximum permissible length (L) of beds and furrows at a given location. At ICRISAT Center it was assumed (rather arbitrarily) to be 100 m, which experience with overflow and breaching of beds has confirmed as adequate. The procedure described below is to determine the length (L) for a specific location on the basis of soil, rainfall, and furrow geometry.

Table 25. Relative contribution by indicated storm categories to runoff, soil loss, and crop yields in small plots in Alfisols, ICRISAT Center, 1981.

Storm category (based on rainfall in mm)	Total rainfall (mm)	Mulch rate (t/ha) 0	2.5	5.0	10.0	SE
		Runoff (mm)				
>50	190	132	118	95	69	±3.2
50-20	437	244	176	112	32	±3.8
<20	67	14	2	1	0	±0.6
Total		390	296	208	101	±4.9
		Soil loss (t/ha)				
>50	190	1.53	1.06	0.90	0.76	±0.102
50-20	437	4.17	2.36	1.49	0.42	±0.114
<20	67	0.23	0.02	0.01	0.01	±0.005
Total		5.93	3.44	2.40	1.19	±0.221
		Crop yield (kg/ha)				
Sorghum		2790	2800	2980	3040	±116
Pigeonpea		1340	1390	1500	1810	± 99

Criteria for deciding the length of irrigated furrows are governed by irrigation efficiencies. Using the schematic plan given in Figure 21, the following analysis for safe and efficient disposal of runoff as the primary function of furrows in the BBF system may be adopted:

$$A = W\ L \quad \ldots\ldots (1)$$

where

A = catchment area of a single furrow at its outlet end,

W = distance from center of a bed to the center of adjoining bed,

L = length of run of furrows, and

$$q_p = (r = i)\ W\ L \quad \ldots\ldots (2)$$

where

q_p = peak rate of runoff coming to the furrow outlet,

r = peak rainfall intensity (for a specified recurrence interval and time of concentration)

i = infiltration rate.

The discharge capacity of the furrow channel can be given by:

$$q_f = a\ \frac{[R^{2/3}\ S^{1/2}]}{n} \quad \ldots\ldots (3)$$

where

q_f = discharge capacity of the furrow channel,

a = cross sectional area of the furrow channel,

n = Manning's roughness coefficient,

R = hydraulic radius, and

S = gradient of the furrow.

Apparently,
to eliminate overflow of furrows $qp < qf$.
In a critical case where $qp = qf \quad \ldots\ldots (4)$

$$(r - i)\ W\ \ L = \frac{a\ [R^{2/3}\ S^{1/2}]}{n} \quad \ldots\ldots (5)$$

$$L = \frac{a\ [R^{2/3}\ \ S^{1/2}]}{(r - i)\ W\ n} \quad \ldots\ldots (6)$$

Thus equation (6) can be used in deciding the maximum length of run for a given situation.

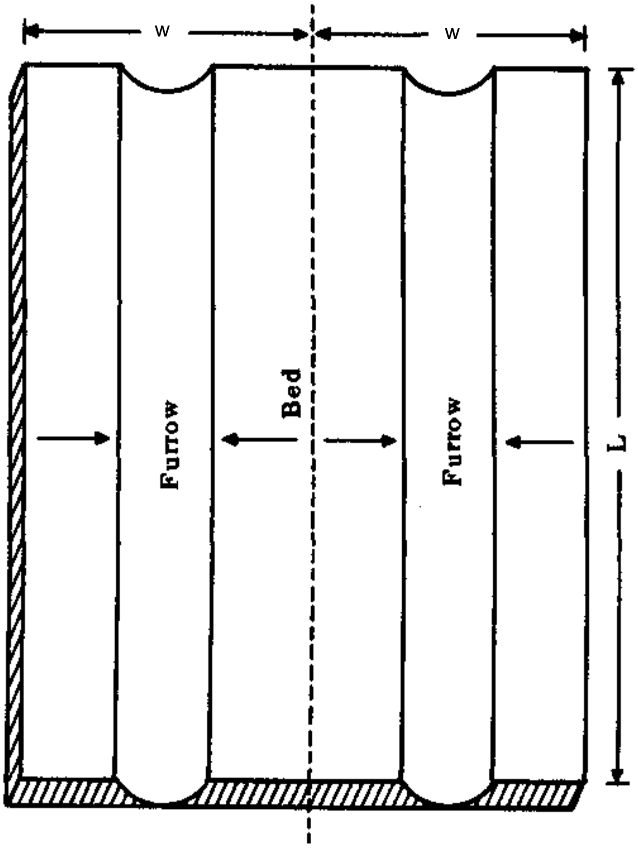


Figure 21. Schematic sketch showing catchment area of a furrow in the broadbed-and-furrow system.

The parameters a, R, W, and S depend on furrow geometry and chosen gradients; r depends on rainfall characteristics; i and n are governed by the soil and its physical conditions. A suitable factor of safety is desirable in equation (6), to account for spatial and time variabilities.

We attempted to use equation (6) to determine L for Vertisols at ICRISAT Center. When the beds and furrows are formed, furrow depth is about 15 cm, and is reduced to about 10 cm by subsequent rains.

Cross sectional area of a furrow, $a = 0.025$ sq m
Wetted perimeter, $p = 0.433$ m
Hydraulic radius, $R = 0.058$ m
(assuming $n = 0.024$ for bare channels)

Peak rainfall intensity at Hyderabad for a 10-

year interval and 5 to 10 minutes' concentration
= 133 mm/hr = 0.133 m/hr.
Terminal infiltration rate in Vertisols
= 0.2 mm/hr = 0.0002 m/hr;
those values in equation (6) give us

$$L = \frac{0.025(0.058)^{2/3} \quad (0.006)^{1/2} \quad (3600)}{(0.133-0.0002) \quad (1.5) \quad (0.024)}$$

$$= \frac{1.045}{0.0048} = 217.7 \text{ m}$$

So our assumed value of L = 100 m has a safety factor of about 2.18. If a designer accepts a lower factor, the length of run can exceed 100 m. But the procedure should help one decide the length of run of beds and furrows at new locations.

Effect of Trampling Wet Soil in Vertisol Bed Zones

This study was conducted in 1981/82 on plots where either chickpea or safflower was grown after maize in a Vertisol watershed. The experimental area had been under the broadbed and furrow (BBF) system of land management 6 years. In that management system, the compaction due to animals and equipment wheels normally was limited to the furrow zone, and the bed zone was used for cropping.

When we harvested and hauled the maize crop in early October, the soil was wet from intermittent rain. Laborers walked repeatedly on top of some beds in the cropping zone. Noticing puddling of soil in the beds, we randomly marked six

Soil compaction at the center of the broadbed, is greater compared to the sides where the soil is more friable. Walking on the bed when it is wet, a common practice of farm labor, compacts the soil which results in the formation of clods in subsequent tillage and reduces seed-soil contact. ICRISAT scientists now advise farmers to walk in the furrow not on the bed.

such beds in each area for further study. Six untrampled beds in each were the checks.

Chickpea and safflower were planted in maize stubble after a shallow cultivation on the bed zone without preparing a conventional seedbed. During cultivation and planting, draft of the wheeled tool carrier was significantly higher on trampled beds than on normal beds. The mean bulk density of trampled beds was 1.42 ± 0.01 g/cc; of normal beds, 1.31 ±0.01 g/cc. Stand establishment of both chickpea and safflower on trampled beds was a problem with the reduced tillage used. Populations and grain yields of both chickpea and safflower were significantly reduced on trampled beds (Fig.22).

This study indicates that movement upon or working of Vertisol soil should be minimized when soil moisture is above plastic limit. When it is crucial to do certain operations while the soil is wet, only the furrow zone should be used for movement.

Low-cost Tank Sealants

We tried soil dispersants, soil cement lining, and improving soil gradation to reduce seepage rates in small tanks on Alfisols and Vertisols. None was successful for Vertisols. Soil cement lining reduced the seepage rate on Alfisols to as low as 8.21 liters/sq m per day, a reduction of 97.2%. But when the lining was exposed to the sun, it cracked so seepage rates when the tank was refilled exceeded the original rates. The performance of soil cement lining on Alfisols is being studied further.

Time Study on Wheeled Tool Carriers

Wheeled tool carriers have proved suitable for new crop-management systems that permit two crops a year under certain dryland conditions. To determine more precisely the economics of

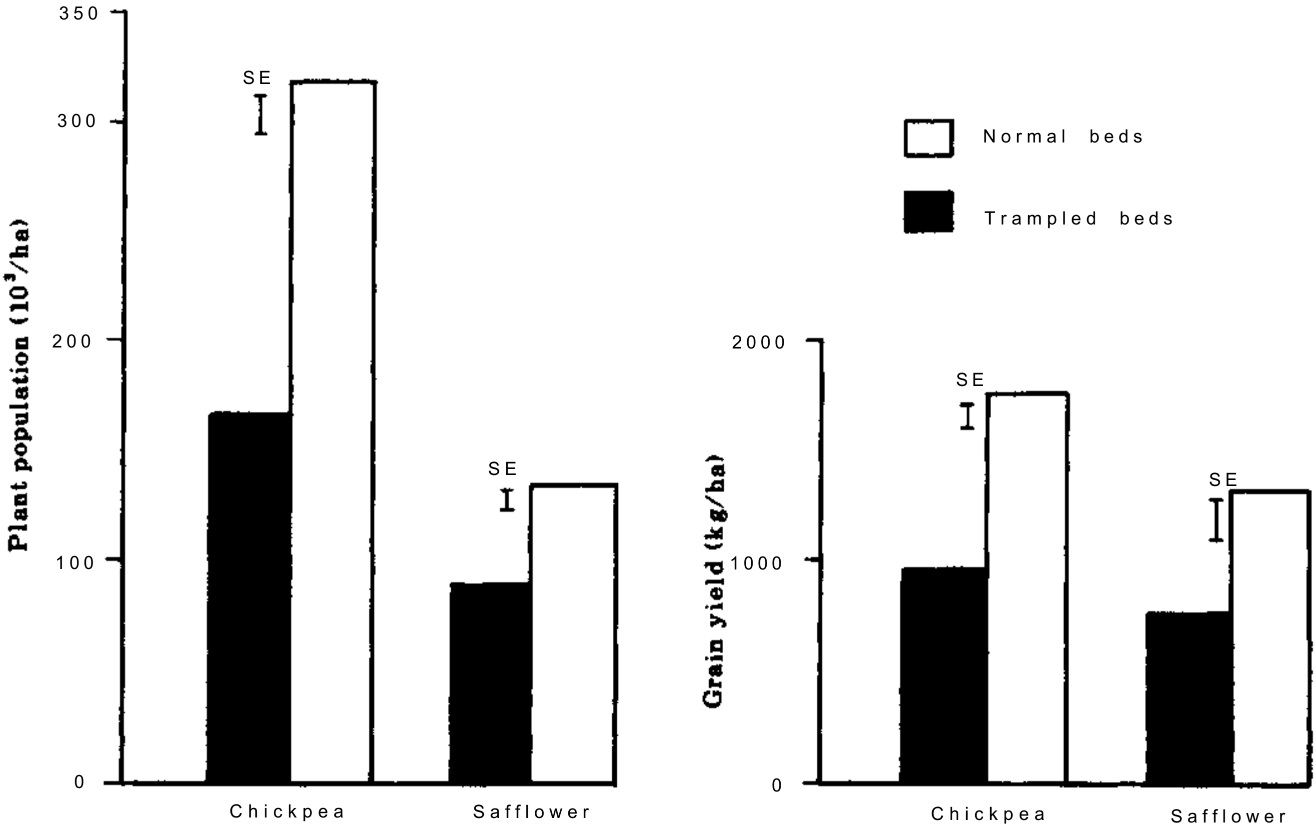


Figure 22. Effect on chickpea and safflower of trampling wet soil in the bed zone on a Vertisol, ICRISAT Center, 1981/82.

wheeled tool carriers, it is important to estimate the maximum area that can be farmed with one carrier. Knowing that will make it easier to interest farmers in the new management system and convince them of the profitability of wheeled tool carriers and the complete system. A wheeled tool carrier with a reasonable set of implements—costing the equivalent of about U.S.$ 1200—is the major investment required.

The maximum area is governed by two factors: the time available to complete each operation, which is usually dictated by weather conditions, and the area required to make the machine economically profitable.

In determining the maximum area of a wheeled tool carrier, our primary objectives were to determine: field capacity and field efficiency under different conditions, and the influence of such variables as management system, field shape, and length of run.

We also needed a practical method to collect reasonably accurate field data. The method we devised is used for collecting data in our on-farm research as well as at ICRISAT Center.

The total time required to do a particular operation is divisible into these parts:

1. Machine preparation time at the farm,
2. Travel time to and from the field,
3. Machine preparation time in the field before and after the operation,
4. Theoretical field time,
5. Turning times and time crossing grassed waterways,
6. Time machine is stopped for adjustments,
7. Auxiliary time, such as refilling seed,
8. Breakdown and repair time (in the field), and
9. Rest and operator's personal time.

Field efficiency is expressed as 4/(4+5+6+7+8); 1, 2, and 3 are not included in field efficiency because their fixed values for a certain operation depend on local circumstances, not the area cultivated. Term 9 is not included because it varies widely and would affect the reliability of field efficiency. Major repairs and preventive maintenance are not included in 8 above.

Conditions that affect field efficiency are: theoretical field capacity of the machine, machine maneuverability, field size and shape, soil and crop condition, and climatic conditions.

Field efficiency is further influenced by the total economic performance consisting of: machine performance (width and breakdown time), power performance (type and condition of draft power), and operator performance (experience, motivation).

Machinery operating-time data were gathered at ICRISAT Center the past few years, with chart recorders attached to most of the wheeled tool carriers. The recorder has a pendulum that vibrates and marks the chart while a machine is moving. In collecting data, we assumed that field capacities and field efficiencies could be obtained from those data (ICRISAT Annual Reports 1977/78 and 1978/79). Information on starting and finishing time, type of operation, date, and field size were recorded separately. The data permitted us to calculate an approximate field capacity and field efficiency—somewhat less precise than specified by the data set (Table 26).

The most accurate way to collect the required data is by personal observation and recording time in minutes. Then one knows exactly how much time is spent on each category. With the measured farmed area and time recordings, one can calculate field capacities and field efficiencies. The disadvantages of this method are the time required to record the data and its being limited to one tool carrier at a time.

No separate experiment was set for the recordings but data on current operations were recorded.

We wanted average theoretical field capacities and actual field capacities for each operation under as many different conditions as possible without influencing the operator. So we observed work done under normal conditions at the regular time. That prevented us from measuring draft required and statistically checking the influence of some variables.

Table 26. Summary of observations on tool carrier operations on Vertisol watersheds at ICRISAT Center.

Mgt systems	Tool carrier	t.f.c.[1] (ha/hr) No. of obs	t.f.c.[1] (ha/hr) Mean	t.f.c.[1] (ha/hr) SE	a.f.c.[2] (ha/hr)	f.e.[3] (%)	f.t.[4] (min)	Rest time (% of f.t.)	Auxiliary time (% of f.t.)	Breakdown time (% of f.t.)	Turning time (min) No. of obs	Turning time (min) Mean	Turning time (min) SE
BBF[5]	Trop[6]	128	0.42	±0.037	0.22	52	364	23	7	3	114	0.65	±0.015
BBF	Nikart	144	0.44	±0.033	0.25	57	467	26	5	2	109	0.77	±0.021
Flat	Trop	77	0.45	±0.039	0.25	56	216	9	7	5	70	0.60	±0.022
Flat	Nikart	27	0.38	±0.037	0.18	47	118	22	21	0	15	0.66	±0.026

1. t.f.c. = theoretical field capacity.
2. a.f.c. = actual field capacity.
3. f.e. = field efficiency.
4. f.t. = field time.
5. BBF = Broadbed and furrow.
6. Trop = Tropicultor.

In addition to observations at ICRISAT Center, some were done in the watersheds in Aurepalle, a village of on-farm research in the FSRP. That permitted us to compare the performance of ICRISAT employees and bullocks with the performance of farmers and their bullocks.

Earlier available data are of the actual field capacities. Even though the earlier data on actual field capacities were not calculated with the same definition now used, the earlier data provide approximations. Moreover, actual field conditions always fluctuate rather widely because many factors influence them. Fluctuations of actual field capacities of different operations in 1976 under the simpler measurement system and in 1980 under the more rigorous measurement system are given in Table 27.

To simplify data collection, we designed or modified some relatively simple instruments. A chart recorder was modified to be shut off when movements such as transportation are not to be recorded so field time only can be recorded. Reasons for stops can be obtained from the operator each day. A revolution counter, attached to one wheel, was designed to operate only when implements are in the working position. Thus distance traveled could be recorded. The distance multiplied by machine width gave area covered. Data from operations in two fields, collected two ways (time study by personal observations and with the modified chart recorder and wheel revolution counter), are shown in Table 28.

Theoretical field capacities did not differ within groups of the same operation; that is, soil type, management system, or tool carrier was

Table 27. Range of actual field capacities in two seasons for indicated operations, ICRISAT Center.

Operation	Actual field capacity (ha/hr) 1976	Actual field capacity (ha/hr) 1980
Plowing	0.11-0.22	0.11-0.30
Ridging	0.12-0.43	0.25-0.35
Cultivating	0.10-0.46	0.13-0.34
Fertilizer application	0.17-0.42	0.14-0.31
Planting	0.17-0.37	0.12-0.23

Table 28. Comparison of tool carrier operational data collected by two methods, ICRISAT Center.

Observations	Field 1		Field 2	
	Method of recording data			
	1[a]	2[b]	1	2
Total field time (min)	105.8	106.0	93.5	94.0
Resting time (min)	31.7	32.0	7.4	9.0
Area (ha)	0.31	0.32	0.41	0.41
Total field capacity				
mean (ha/hr)	0.47	0.49	0.46	0.51
SE	±0.037	±0.010	±0.012	±0.037
No. of observations	55	22	54	14
Actual field capacity (ha/hr)	0.25	0.25	0.28	0.29
Field efficiency (%)	52	50	60	56

a. Time study by personal observation.
b. Time study with instrumentation.

not a significant influence, with one exception—the theoretical field capacity of the plowing operation on Alfisols at ICRISAT Center was considerably higher than the theoretical field capacity on Alfisols at Aurepalle (0.48 and 0.34 ha/hr, respectively). The difference likely stemmed from higher draft requirements at Aurepalle. It emphasizes that draft should be measured as one of the factors in field capacity. Plowing at ICRISAT Center was in mid-September when soil conditions were good; at Aurepalle it was in early October after the soil had dried and become hard.

The difference between turning times at Aurepalle and at ICRISAT Center was striking. Turning times at ICRISAT were 40 to 50% longer than at Aurepalle. At ICRISAT the bullocks stopped at the end of each run and the implements were lifted. In Aurepalle the implement was lifted and lowered with the tool carrier moving.

Development of a Rolling Type Soil-crust Breaker

A soil crust impedes, and may prevent seedling emergence, unless it is kept moist by frequent wetting or broken mechanically. Wetting is often impossible or unpractical, so small fanners need equipment to break the soil crust above rows of germinated seeds. We developed and tested a rolling crust breaker at ICRISAT Center.

Small seeds like pearl millet are generally planted about 30 mm deep, so the crust breaker's spike length should be less than 30 mm. A survey at ICRISAT Center showed 10- to 20-mm thick soil crusts on the Alfisols, so the optimum spike length is 20 to 30 mm. We selected 25 mm. The rolling drum's diameter of 150 mm was based on ease of fabricating and manually operating the equipment. A prototype of the crust breaker was fabricated and mounted on two types of frames; one for manual operation, the other to attach to a bullock-drawn tool carrier. We evaluated both in Alfisol fields. Pearl millet and sorghum genotypes were planted manually, and about 35 mm of water was applied by a sprinkler 2 m above, to produce a reasonably uniform and hard crust.

The day before expected plant emergence, the crust was dry and its strength ranged from 2 to 2.5 kg/cm^2, measured with a pocket penetrometer. Average soil moisture content in the top 10 cm was 8% and soil temperature near the seeds ranged from 35° to 37°C. Temperature and moisture conditions were judged favorable for seedling emergence.

The crust breaker was used to break the soil crust on seeded rows 1 day before plants were expected to emerge. All genotypes emerged and became established. Emergence counts were taken 1 week later (Table 29).

Design and Development of a Planter for Wheeled Tool Carriers

Until 2 years ago the imported Ebra-unit, inclined-plate planter was used with wheeled tool carriers to sow all crops. The metering mechanism was driven from the press wheel. When four units were attached to the toolbar, it made planters heavy to put into transport position. High friction in rotating the metering plates and improper setting of bevel gears lowered performance. Because soil sticking to the press wheels caused gaps and slippage, the planter was redesigned to match the fertilizer drill described in the ICRISAT Annual Report 1981.

After investigating various metering mechanisms, we decided to continue using the inclined-plate method. It has several advantages:

1. A wide range of seed sizes can be planted.
2. A wide range of between-plant spacings can be achieved.
3. Different seeds can be sown simultaneously in adjacent rows, which is highly desirable for intercropping.

The planter consists of a rectangular sheet metal hopper with one side inclined 35 degrees from vertical and lined with a Bakelite sheet to reduce friction between the metering plate and base surface. The hopper has four compartments so different seeds can be metered for an intercrop.

Bakelite plates with appropriate-sized cells on the periphery permit metering different seeds. The metering plate is held in position with a compression spring adjusted by a nut. A bicycle sprocket and disc (with holes spaced at an equal circumferential distance to the pitch of the sprocket) replace the bevel gears of the imported machines and reduce the cost substantially. Seed rates can be varied by selecting a metering plate with the desired number of cells.

The planter is mounted on the same frame that supports the fertilizer drill so seed and fertilizer may be applied at one time. Power to drive the system is from the left wheel of the tool carrier through a chain and sprockets. A clutch mounted on the drive shaft lets the operator engage or disengage the power as desired.

We designed a furrow opener requiring relatively low draft that can place seed and fertilizer 10 to 12 cm deep, acceptably separated, and it does not clog easily in wet soil. It consists of two shoe-type, narrow furrow openers bolted to a T-frame, the front one for fertilizer, the rear one for seed. Fertilizer is placed 45 mm below and 40 mm to one side of the seed. The seeds are covered by soil pushed from both sides by a covering device.

The covering devices and press wheel to compact the seed also are attached to the T-frame. Additional weight must be added to the wheel to increase compaction. The covering devices and press wheel are easy to attach or remove, so either or both are easily used, depending on soil condition.

After running the prototype planter on a test bench 50 hours, we tested it in the field to study the performance of metering maize, pigeonpea,

Table 29. Seedling emergence (%) of pearl millet under crusted and mechanically broken crust conditions of soil, ICRISAT Center, 1982.

	Pearl millet genotypes						
Treatment	WC-C 75	ICMS 7703	D-2395	SC2-191	D-299	MEC 91	SSC 93
Crusted	33	46	0	0	3	2	3
Crust broken	42	61	23	56	45	37	50
SE	±5.0	±6.1	±6.2	±9.4	±9.5	±9.1	±7.6

chickpea, sorghum, pearl millet, castor, mung, and groundnut seeds (Table 30). The pearl millet stand was not recorded because it was poor-likely from unfavorable soil conditions and low January temperatures. But based on the number of pearl millet seeds sown we believe it should be possible to obtain acceptable plant populations.

It is difficult to obtain the desired groundnut plant population with the new planter, as the number of cells in the metering plate cannot be increased because the seed is so large; some design modification will be necessary.

Testing and Evaluating Prototype Planters

In addition to the new inclined-plate planter designed for wheeled tool carriers, we developed a prototype low-cost planter for the Akola cart by using a Planet Jr. system—a unit planter with a gravity feed and agitator. Metering is by a fixed disc with a range of hole sizes. The seed from a single unit planter is dropped on a wooden see divider, which is commonly used to meter see in a local drill, and to divide seed for two or more rows simultaneously. The drive to the agitator comes by chain and sprockets from a spoked wheel. Both the planter unit and spoke wheel-drive assembly were attached on the toolbar.

Five types of planters were tested in the Vertisol watershed for planting sorghum (CSH-6) and maize (Deccan hybrid 101). The planters in the five treatments were:

T_1. Imported Ebra unit, inclined-plate planter driven by the press wheel.

T_2. Imported Ebra unit, inclined-plate planter mounted on the tool carrier frame and driven by a common shaft.

T_3. Locally designed, inclined-plate planter mounted on the tool carrier frame and driven by a common shaft.

T_4. Planet Jr. unit planter with a wooden seed-divider.

T_5. Local Gorru multi-row seeder with a wooden seed-divider to meter seed by hand.

Stationary calibrations at the workshop showed that the five planters could not be adjusted to give the same seed rate (Table 31), an important factor determining plant to plant spacing. Hand metering by the local Gorru had the lowest seed rate even though the best of three skilled persons did the hand metering. But he achieved only about 50% of the desired seed rate. The between-row spacing of the Gorru was 30 cm for sorghum and 50 cm for maize, spacings

Table 30. Recommended and actual plant populations obtained from 4-row prototype planter, 1CRISAT Center, 1982.

Crop	Recommended row spacing (cm)	Seed rate adjustment position	Plant population/ha	
			Recommended	Actual
Sorghum (sole)	45	Low	180000	220000
Sorghum (intercrop)	90	High	180000	187000
Maize	90	High	60000	80000
Pearl Millet (sole)	45	Low	180000	—[a]
Pearl Millet (intercrop)	90	High	180000	—[a]
Pigeonpea	150	High	40000	53000
Chickpea	30	High	330000	294000
Castor (intercrop)	150	High	50000	47000
Mung	30	High	330000	330000

a. —poor emergence; data not recorded.

Table 31. Effect of type of seeding equipment on establishment and yield of maize and sorghum on an Alfisol, ICRISAT Center, 1981/82 (plot size = 15 m^2).[1]

Crop	Seeding equipment	Seeding[2] rate (no/15 m^2)	Mean spacing between plants (cm)	Yield (kg/ha)
Maize	T_1-Ebra, press wheel	200	21	2350
	T2-Ebra, common shaft	160	19	2350
	T_3-Local, common shaft	160	32	1800
	T4-Planet Jr.	240	19	2880
	T_5-Local Gorru	120	21	2290
	SE		±2.2	±207
Sorghum	Ti-Ebra, press wheel	750	11	2750
	T2-Ebra, common shaft	750	9	2120
	T_3-Local, common shaft	600	12	2680
	T4-Planet Jr.	600	9	2070
	T_5-Local Gorru	300	23	2010
	SE		±2.5	±453

1. Maize and sorghum sown in two and three rows per 150 cm planter width.
2. Laboratory germination rates: maize, 97%; sorghum, 55%.

commonly used by farmers. The between-row spacing of all other planters was 45 cm for sorghum and 75 cm for maize. The Planet Jr. unit delivered a seed rate on the high side because the next smaller hole gave a low seed rate.

The differences in seed rates of the planters used in T_1, T_2, and T_3 arise from various metering-plate cell sizes, slight variations in the metering plate speed, and slight differences in power transmission.

Two methods of analysis were considered appropriate for judging the planters. The first was to make frequency distribution tables to show percentages of plant spacings in different spacing ranges. That information is used to plot histograms and to indicate the percentage of between-plant spacings within the optimum range. The optimum range is considered the theoretical mean spacing ± 5 cm. The theoretical between-plant spacing for maize is 20 cm; sorghum, 10 cm; so optimum spacing ranges are 15-25 cm and 5-15 cm, respectively. The second method compares mean spacings and coefficients of variance obtained from different planters.

The first planting method, the Ebra planter driven by a press wheel, gave the most uniform plant to plant spacings in the optimum range for maize. Less uniformity with the other four likely resulted from the long drops of seeds between the metering device and the furrow opener (from about 1 m in the local seed drill to 1.5 m planters mounted on the tool carrier). Seed drops less than 30 cm in the Ebra planter driven by a press wheel.

The locally designed prototype planter gave the highest uniformity (46%) of plant to plant sorghum spacings in the optimum range. The next best (43%) was the Ebra planter driven by the press wheel and the same planter mounted on the chassis. With sorghum the length of seed drop from the metering plate to the soil had no effect on plant to plant uniformity, probably from sorghum's higher seed rate than maize's and shorter plant to plant spacings. Also sorghum seed being more uniformly round may let it move more smoothly than maize in the tube.

The analysis of variance for maize shows significant differences (*P*<0.05) for mean plant to plant spacing, variance, and CV. The yield of maize is not statistically significant, which indicates that differences in mean spacing, variance, and CV due to the planting mechanisms do not affect maize yield.

The analysis of variance for sorghum shows a significant difference (*P*<0.05) only in the mean plant to plant spacing. Variance, CV, and yield show no significant differences, again clearly indicating that yield is not significantly affected by mean, variance or CV of plant to plant spacing, within the range of our planters. We will continue to test different planters, but our experience to date indicates that good results can be obtained by using the economical local drill with hand metering so long as there are no labor shortages at seeding time.

Intercropping

Groundnut/Pigeonpea

During 1982 we initiated studies on groundnut-/pigeonpea intercropping to examine its potential for increased productivity. At final harvest, sole groundnut yielded 6780 kg/ha of total dry matter and 4094 kg/ha of pods; sole pigeonpea, 5893 kg/ha dry matter and 1486 kg/ha grain. The total dry matter yields of intercrop groundnut were 76% and 77% of the sole crop in the 1:3 and 1:5 row arrangements and total dry matter yields of intercrop pigeonpea were 75% and 70% of the sole crop in the 1:3 and 1:5 row arrangements. Pod yields of intercrop groundnut were 77% and 83% of the sole groundnut in the 1:3 and 1:5 row arrangements, respectively, and

Our pigeonpea/groundnut intercropping tests gave 58% grain or pod yield advantage over those from sole crops—with either 1:3 or 1:5 pigeonpea.groundnut. Pod yields from the intercropped groundnut were 77 to 83% of the sole crop: pigeonpea grain yields 75 to 81% of the sole crop.

grain yields of intercrop pigeonpea were 81% and 75% of the sole crop in the 1:3 and 1:5 row arrangements. So the final grain or pod yield gave a 58% advantage over sole cropping with either the 1:3 or the 1:5 intercrop system.

We continued stability studies on sorghum-/pigeonpea (2:1 row arrangement), sorghum-/millet (1:1), millet/groundnut (1:3), and pigeonpea/groundnut (1:5) in nine situations across ICRISAT Center, ranging from shallow Alfisol to deep Vertisols and incorporating different intensities of weeding and plant protection. Detailed stability analyses will require more data, but the performance of the crops in sole and intercrop situations across different environments furnishes more information on intercropping's role in stabilizing yields.

Sorghum Genotypes

Studies of genotypes for cereal/low-growing legume intercrops at ICRISAT Center have involved sorghum or millet intercropped mainly with groundnut. In most of the African and Latin American SAT, cowpeas (*Vigna unguiculata)* are an important source of protein for small farmers, so we included cowpeas in the genotype evaluation program this year and intercropped cowpea C-152 with sorghum genotypes of different genetic backgrounds: 12 sister lines, 6 improved lines, 3 hybrids, and 2 local types. The 23 sorghum genotypes were allotted to main plots, and the two cropping systems (intercrop and sole) to subplots. The sowing pattern was 1 sorghum:2 cowpeas. The experiment was on a medium-deep Vertisol. The sorghum canopy ranged from 80 to 250 cm to flag leaf height with canopy widths from 45 to 95 cm. The genotypes flowered between 59 and 82 days after emerging. Their leaf types ranged from short-erect to floppy. Canopy height or width correlated negatively with light transmission to the cowpeas.

Sorghum-genotype grain yields ranged from 370 to 6200 kg/ha in sole cropping and from 420 to 3780 kg/ha in intercropping. Associated cowpea grain yields ranged from 620 to 1180 kg/ha; as the sole crop, cowpeas yielded 1600 kg/ha.

Sorghum had equivalent ratios (LERs) for grain yield in all the genotypes showed a good advantage in intercropping, since LERs were invariably above their expected 0.33, ranging from 0.40 to 1.12. Sister sorghum lines' LERs ranged from 0.50 to 1.00; hybrids, from 0.61 to 0.79; improved lines, from 0.40 to0.76; and local types, from 0.79 to 1.12. Cowpeas' LERs averaged below the expected 0.67 but cowpeas with some sorghum genotypes had LERs up to 0.80.

The overall performance of intercropping across all sorghum genotypes gave an advantage of 28% (LER 1.28) for grain yield. For some sister lines, the advantage was 50%. The hybrids and improved lines improved yields from 17 to 20%.

Sole sorghum yield and intercrop sorghum yield were well correlated (r = 0.87). But deviations from the fitted line for some shorter (M66433, 2219B, S1021) and medium (CSH-5, CSH-9, SPV-351) sorghum genotypes were large enough to make their interaction with the cropping systems highly significant.

But consideration of the LERs gives a different result from that obtained by comparing grain yields from sole and intercropping; the higher-yielding genotypes in sole sorghum wenrnot the most suitable for intercropping. Sole sorghum yields accounted for only 20% of the variation in sorghum LER. In addition to height and maturity of sorghum genotypes, other characters appear to be involved in determining sorghum's performance in intercropping with a low legume; some of these are leaf area, leaf length, leaf arrangement, and relative growth rate of the two crops. All affect grain yields without depressing cowpea yields.

Diagnosing Iron Deficiency in Groundnut

Temporary waterlogging of alkaline soils in southern India commonly causes groundnut to develop temporary chlorosis, but only over irregular areas. The presumed cause is iron deficiency, because the foliar symptoms are identical with those of iron deficiency. But temporary waterlogging increases the availability of iron, because reduced aeration reduces ferric-iron to ferrous-iron. It is presumed that the restricted aeration increases carbon dioxide concentrations in the soil and thus increases bicarbonate in the soil solution; increased uptake of bicarbonate interferes with iron metabolism in plants.

We lack satisfactory methods to assess the iron status of plants. Standard predictive soil tests are not effective for waterlogged soils, and tissue analysis for total iron content of tissue has not been satisfactory in the past for indicating the iron status of chlorotic leaves. That led us to examine the hypothesis that the iron status of plants may be assessed by the ferrous iron content of the tissue; recent work has shown that tissue content of ferrous iron can be estimated by extracting fresh tissue with O-phenanthroline (extractable iron).

Results were presented last year for leaves collected randomly from chlorotic and healthy areas of groundnut in ICRISAT's precision fields; the extractable-iron contents of leaves from chlorotic areas were substantially lower than those of leaves from healthy areas. The total iron content of the leaves was, in keeping with results obtained by previous workers, commonly higher in the chlorotic leaves.

Our preliminary studies this year were to minimize sampling errors by examining the extractable iron content of leaves of groundnut plants of various ages. That approach was adopted because iron-chlorosis always develops first in the youngest leaves. As expected, the extractable iron contents of the leaves decreased with age of leaf. With the onset of chlorosis, however, extractable iron contents decreased not only in the youngest leaves but also in other leaves. In a later monitoring program, with only one or two selected plant parts regularly sampled and analyzed, only the buds and first unfolded leaf were sampled.

Although chlorosis did not develop severely in the 1981 rainy season, the results indicated that the extractable iron content of young leaves was low on all occasions when the plants were chlorotic (Fig.23). In this and later studies, chlorosis was observed only when the extractable iron contents of young leaves or buds were less than 6 μg Fe/g (fresh tissue). Total iron content of leaf tissue again was shown to be clearly unsuitable as an index of the iron status of the plant; some of the highest total Fe contents were leaves taken when plants were chloritic (Fig.23).

We also analyzed leaves from 8 of 64 breeding entries that showed marked contrasts in severity of chlorosis. The 8 were selected as 2 entries for each of the scored extremes in growth and chlorosis among 64 entries. Their extractable-Fe contents were closely related to the severity of chlorosis, despite the range of genetic material used (Table 32). The extractable-Fe content of the first leaf was a much more sensitive indicator of apparent Fe status than was content of the bud.

On-station Operational Research

Evaluating Cropping Systems

We initiated a series of experiments this year to evaluate several promising cropping systems on an operational scale in the research watersheds for low- and medium-fertility situations. We conducted them on deep, medium-deep and shallow black soils, and Alfisols. Other components of ICRISAT's improved farming systems, such as the wheeled tool carrier and broadbed and furrow system, were incorporated.

Large plots (200-400 sq m) were used to evaluate the operational feasibility of the cropping systems in addition to their production potential and profitability. The experiments were conducted in split-plot design, with two fertility regimes as main plots and cropping systems as subplots. In the low-fertility treatment, no fertilizer was applied in the three black-soil experiments, whereas the Alfisols got 20 kg N and 20 kg P_2O_5/ha. In the medium-fertility treatment, 60 kg N/ha was applied across all soil types (30 kg.N/ha only for leguminous crops) and 30 kg P_2O_5/ha for the three black-soil experiments, and 20 kg P_2O_5/ha for the Alfisols experiment. Eleven cropping systems were evaluated for deep black soils, 6 each for medium-deep and shallow black soils, and 10 for Alfisols. Grain yields and

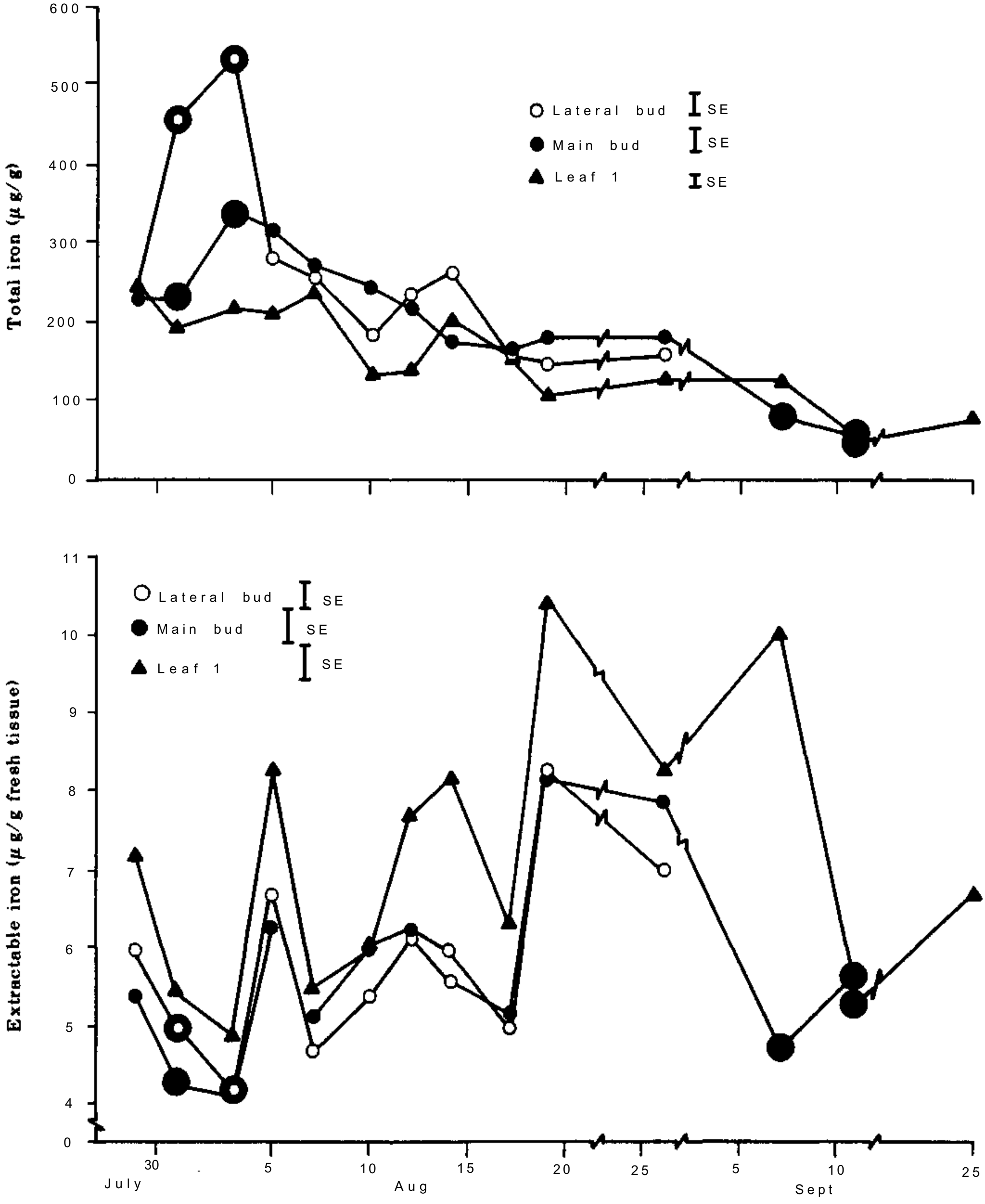


Figure 23. Total (top) and extractable (bottom) iron in young groundnut leaves, Alfisol, ICRISAT Center, rainy season 1981 (encircled points indicate occurrence of chlorosis).

Table 32. Extractable and total iron (µg/g) in bud (Mb) and first fully opened leaf (L-1) of indicated groundnut breeding entries,[1] ICRISAT Center, 1981.

Extent of chlorosis	Plant growth	Breeding entry	Extractable Fe[2]		Total-Fe[3]	
			Mb	L-1	Mb	L-l
Severe	Poor	FESR 12-P5	4.0	4.4	413	302
		FESR 12-P6	4.1	5.0	438	225
Severe	Good	NC Ac 664	4.8	4.5	416	325
		U-1-2-1	4.1	4.4	429	371
Nil	Poor	TMV 2	5.4	9.0	286	196
		Karpovikas	6.5	11.4	267	174
Nil	Good	C.No.501	5.8	9.9	231	202
		E. runner	6.0	10.3	252	263
SE			±0.36	±0.58	±15.1	±7.2
CV (%)			1	8	4	3

1. Leaves sampled 1 Sept 1981, 72 days after sowing.
2. Fresh weight basis.
3. Dry weight basis.

net monetary returns are summarized in Figures 24, 25, 26, and 27. Net monetary returns were calculated by deducting costs of land preparation, labor, seeds, fertilizers, and pesticides from gross returns. Rainfall during the rainy season was 1072 mm, 36% above normal.

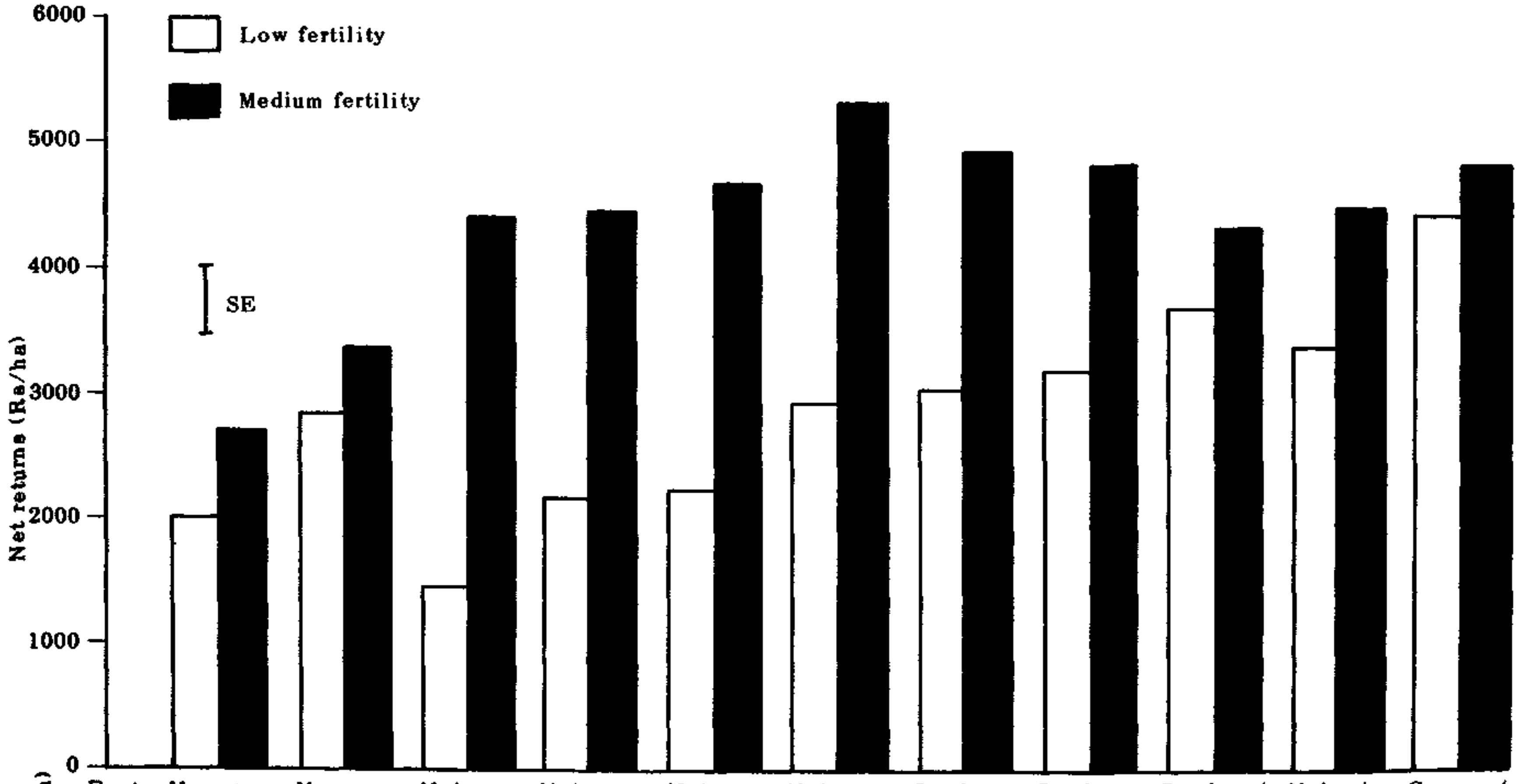
Deep Black Soil

This soil is deeper than 150 cm so its water-storage capacity is high. Of the 11 cropping systems we evaluated, 3 were intercrop systems, 6 were sequential crop systems, and 1 was a relay crop system. Grain yield data from the rainy-season crops (Fig.24) show that in deep black soils, fertilizers substantially increased yields of cereals. Sole maize produced an average of 2580 kg grain/ha under medium fertility, compared with 573 kg/ha under low fertility. Similarly, sorghum produced an average of 3610 kg/ha under medium fertility, compared with 1523 kg/ha under low fertility. Cereal responses when intercropped with pigeonpea were, in general, similar to their sole-crop responses. But intercrop pigeonpea yields were higher under low fertility than under medium fertility. Under high fertility the cereal's competition was much higher than under low fertility. The response of legumes to fertilization was less striking than that of cereal crops.

In general, the intercrop systems gave higher returns than the double-crop systems under low fertility (Fig. 24). Under medium fertility some double-crop systems with maize or sorghum gave higher returns than intercrop systems. Cowpea/pigeonpea intercrop gave the highest returns under low fertility, while maize followed by chickpea gave the highest returns under medium fertility.

Medium-deep Black Soil

The soil used for this evaluation was about 100 cm deep and thus had less water-storage capacity than deep black soils. Of the six cropping systems we evaluated, two were intercrop; three, double crop; and one, ratoon. Their grain yields and net returns are presented in Figure 25. Under both fertility situations sorghum/pigeonpea intercrop was the most profitable. Sequen-

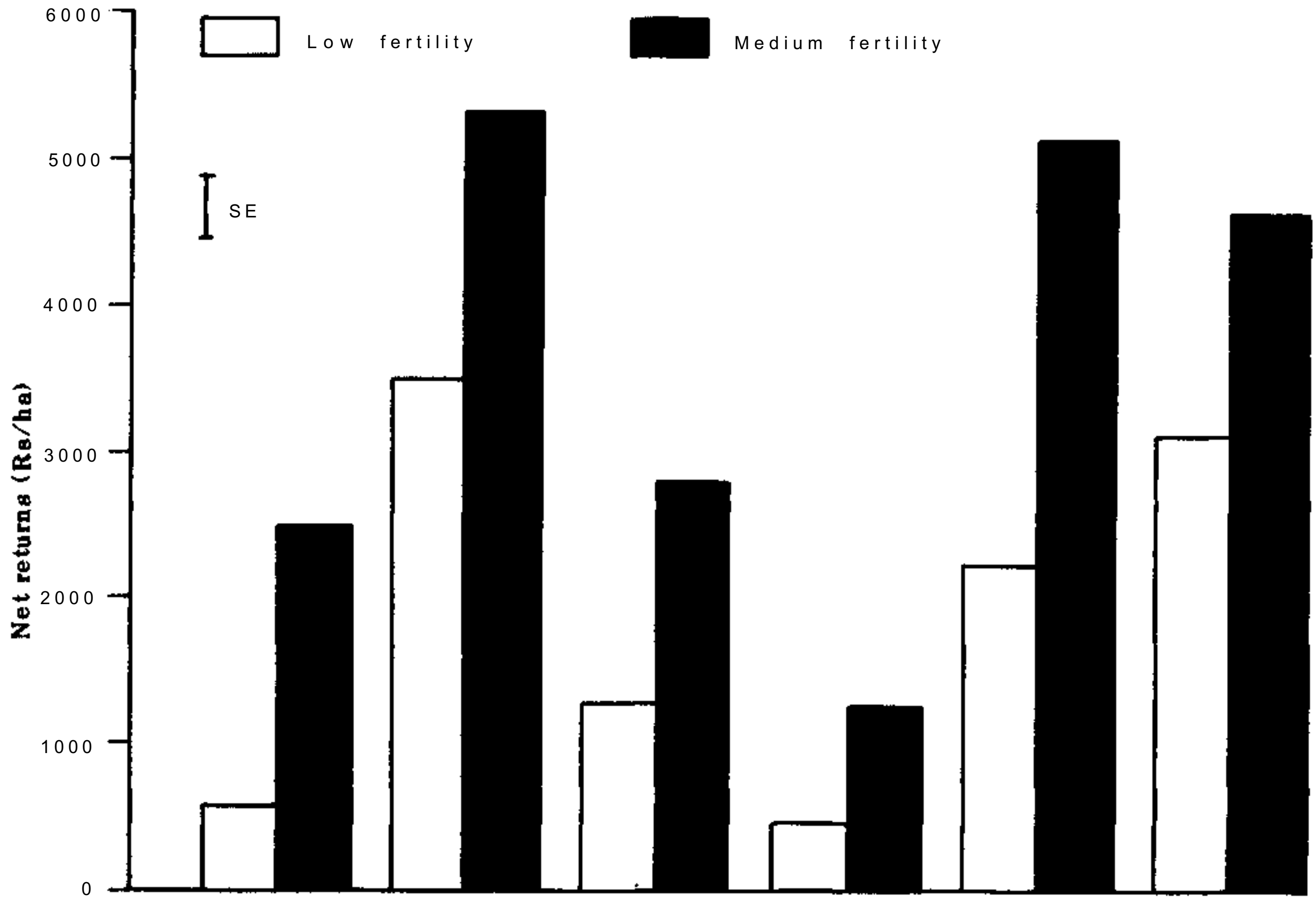


Yields (kg/ha)											
Fert.	Mung+	Mung+	Maize‡	Maize+	Maize+	Maize+	Sorghum+	Sorghum+	Sorghum/	Maize/	Cowpea/
Low	568	532	590	652	467	582	1478	1569	1373	493	594
Med	710	656	2723	2694	2432	2504	3763	3456	3240	2524	657
	Sorghum	Chillies	Chillies	PP	SF	CP	SF	CP	PP	PP	PP
Low	1261	276	221	749	809	1231	765	991	1009	1153	1194
Med	2186	382	343	851	1217	1464	924	1157	746	814	1392

(+ = sequential cropping system; ‡ = relay; / = intercropping; PP = pigeonpea; SF = safflower; CP = chickpea)

Figure 24. Net returns (Rs/ha) and grain yields (kg/ha) from various cropping systems grown on deep Vertisols under low (0-0-0) and medium (60-12-0) fertility on an operational scale at ICRISAT Center, rainy and postrainy seasons 1981/82.

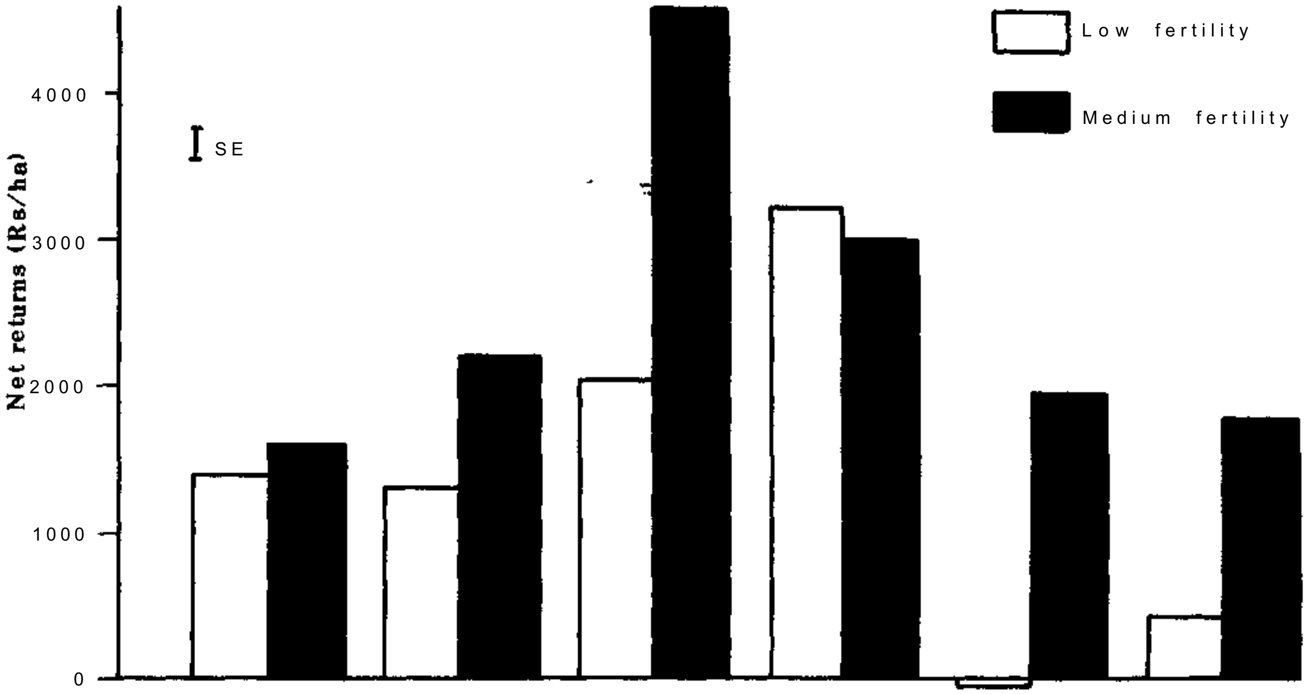
tial sorghum-safflower was nearly as profitable under medium fertility, but not under low fertility. Sequential sorghum-chickpea performed well under both fertility situations, ranking second in profitability under low and third under medium fertility. Those three systems, however, 'were far superior to the others under both fertility situations. The poor ratoon crop in sequential sorghum-ratoon kept profits low despite the favorable moisture environment. The remaining two systems suffered because mungbean, a component in each, was severely damaged by nematodes. In the mungbean/cotton intercrop, cotton yielded well under medium fertility but the high cost of hybrid cotton seed reduced net returns. Sequential mungbean-sorghum was the least profitable of all the cropping systems we evaluated. Both crops performed poorly.



Yield (kg/ha)	Mung/	Sorghum/	Sorghum	Mung +	Sorghum +	Sorghum +
Low	173	1613	1748	224	1483	1723
Medium	141	3783	3788	281	4172	3862
	Cotton	PP	RS	Sorghum	SF	CP
Low	369	853	398	392	450	896
Medium	924	880	442	1630	828	921

(+ = sequential cropping system; /= intercropping; RS = ratooned sorghum; PP = pigeonpea; SF = safflower; CP = chickpea)

Figure 25. Net returns (Rs/ha) and grain yields (kg/ha) from various cropping systems grown on medium deep black soils under low (0-04)) and medium (60-12-0) fertility on an operational scale at ICRISAT Center, rainy and postrainy seasons 1981/82.



Yield (kg/ha)	PP	Sorghum/	Millet/	GN/	Sorghum	Sorghum/
Low	700	343	586	516	516	327
Medium	868	1525	2901	561	3125	1155
	-	PP	PP	PP	RS	Millet
Low	-	594	633	870	-	479
Medium	-	650	680	862	109	1267

(/= intercropping system; PP = pigeonpea; GN= groundnut; RS = ratooned sorghum)

Figure 26. Net returns (Rs/ha) and grain yields (kg/ha) from various cropping systems grown on shallow black soils under low (0-0-0) and medium (60-12-0) fertility on an operational scale at ICRISAT Center, rainy and postrainy seasons 1981/82.

Shallow Black Soil

This evaluation was conducted on a soil with an average depth of 30 cm. Six cropping systems were studied: a long-duration sole crop (pigeonpea), four intercrop systems, and a sorghum-ratoon. Two of the four intercrop systems were eereal/pigeonpea, one was groundnut/pigeonpea, and one, sorghum/millet (Fig. 26).

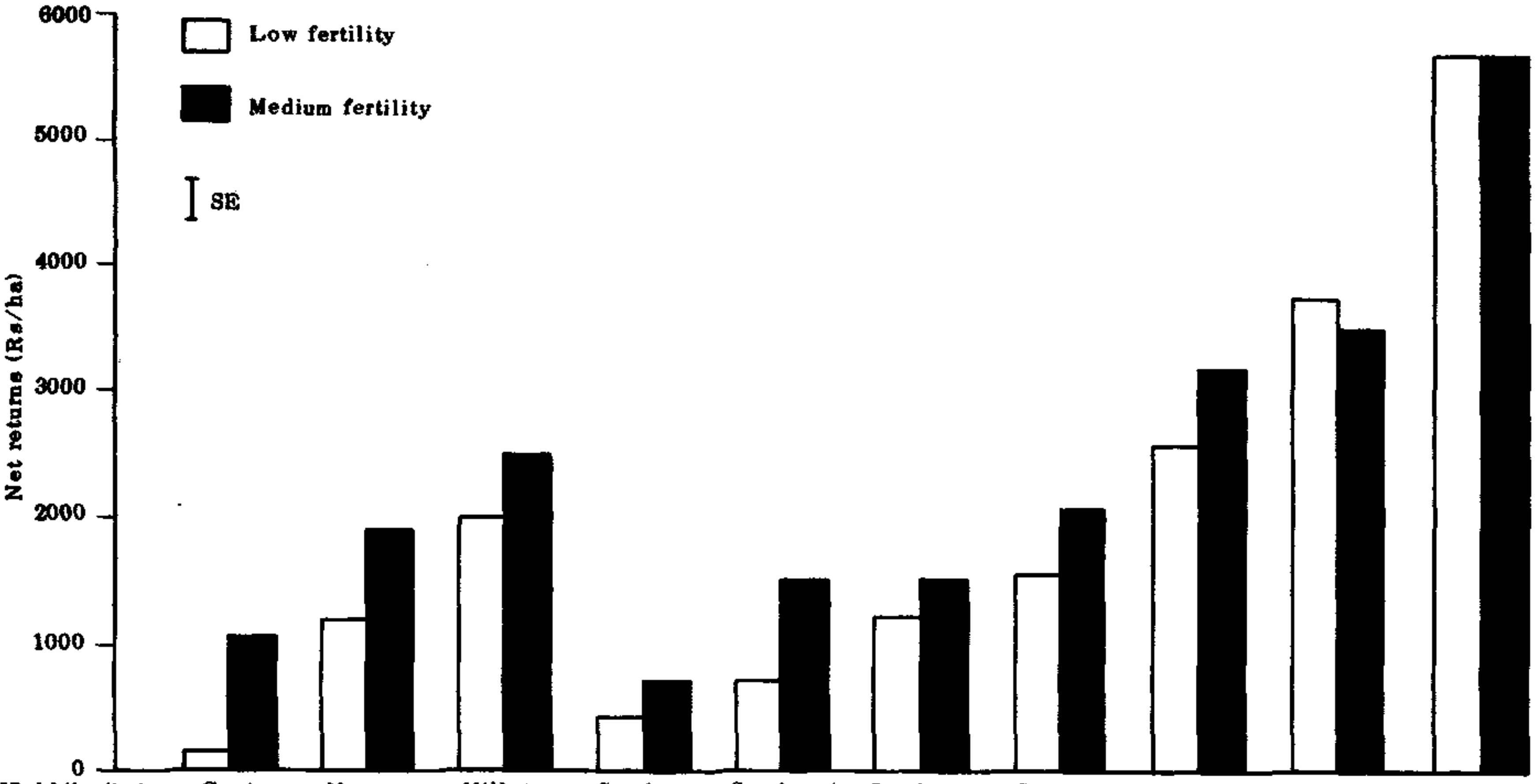
Under low fertility, the four systems with a legume performed far better than cereals alone. Sorghum-ratoon, for example, was not profitable under low fertility; the main crop was poor and the ratoon crop failed completely. Groundnut/ pigeonpea intercrop, both legumes, gave the highest net returns.

Under medium fertility the three pigeonpea-based intercrops, millet/ pigeonpea, groundnut/ pigeonpea, and sorghum/pigeonpea, gave highest net returns, in that order. Returns from sorghum-ratoon were good, but again, the ratoon crop was extremely poor.

Shallow soil's limited capacity to supply water and nutrients restricts cropping potential. Extending cropping on shallow soil seems to be possible only with late-maturing, hardy crops like pigeonpea, and cropping systems with a legume component seem to be highly important on poor soils.

Alfisols

The Alfisols varied from 50 cm to 1 m deep. Of the 10 cropping systems evaluated in this experi-



Yield (kg/ha)	Castor	Mung‡	Millet+	Sorghum	Sorghum/	Sorghum/	Sorghum/	Millet/	Millet/	PP/
Low	537	457	1542	1252	1073	876	1197	1418	752	772
Medium	962	457	2148	1875	1354	1163	1569	1804	847	772
		Castor	HG	RS	Castor	Millet	PP	PP	GN	GN
Low	-	476	532	363	368	951	418	533	1226	1458
Medium	-	858	532	512	654	1118	555	635	1187	1458

(+ = sequential cropping system; ‡ = relay; / = intercropping; HG = horsegram; RS = ratooned sorghum; PP = pigeonpea; GN = groundnut)

Figure 27. Net returns (Rs/ha) and grain yields (kg/ha) from various cropping systems grown on Alfisols under low (20-8-0) and medium(60-8-0) fertility on an operational scale at ICRISAT Center, rainy and postrainy seasons 1981/82.

ment, 6 were intercrop, 1 relay crop, 1 sequential crop, 1 ratoon, and 1 late-maturing sole crop (castor).

The additional nitrogen applied for medium fertility increased grain yields of the cereal crops more than yields of leguminous crops. Cropping systems with either pigeonpea or groundnuts performed much better than the other systems (Fig. 27).

Again the intercrop systems, in general, gave higher returns than the other systems under medium or low fertility. Pigeonpea/groundnut intercrop (both legumes) gave the highest net returns in this soil type also. Returns from sole castor and sorghum-ratoon were the lowest.

The results, similar to those from shallow black soil, clearly highlight two important points: the best way to extend the cropping season in these shallow soils with low water-holding capacity is by intercropping a short-season cereal (sorghum or millet) with a medium- or long-season legume like pigeonpea, groundnut, or castor.

Considering the economic potential of different cropping systems across the four soil environments, the high potential of deep Vertisols is most obvious as 9 of the 11 cropping systems generated net returns exceeding Rs.4000 per hectare under medium-fertility conditions (Fig. 24). For the medium-deep and shallow black soils and Alfisols the range of highly profitable cropping systems narrow to 3 of6 systems, 1 of6, and 1 of 10 as depth of the soil types lessens. Still there was at least one cropping system for each soil type with net returns exceeding Rs.4000 per hectare.

Different Cropping Systems' Effects on Disease Incidence

The cooperative, long-term studies on effects of intercropping and different crop rotations on soilborne fusarium wilt of pigeonpea (F *udum)* and chickpea (F. *oxysporum)* are continuing. Pigeonpea continued, as in the previous 2 years, to show less wilt in intercropping than as a sole crop. The maize/pigeonpea intercrop and two new rotation treatments (cotton followed by susceptible pigeonpea and resistant pigeonpea followed by susceptible pigeonpea) were included in 1982. Initial indications are that maize/ pigeonpea intercrop may be less effective than sorghum/pigeonpea intercrop in reducing wilt. Sorghum or wheat, intercropped with chickpea did not help reduce wilt. Two-year rotation with sorghum, however, delayed chickpea wilt incidence. (The Pigeonpea and Chickpea sections of this report give more details).

Cooperative studies on intercropping effects on the foliar diseases of cercospora leaf spot and rust in groundnut also are continuing. In addition to the pearl millet/groundnut combination studied last year, we included sorghum/groundnut this year, and an additional row arrangment of 1 cereal: 1 groundnut. Results this year confirmed trends from last year. Initial indications are that a cereal intercrop reduces foliar diseases in groundnut.

Weed Management for Cropping Systems

The main objective of weed research remains to design and evaluate economically feasible weed management systems for alternative and improved cropping systems developed by ICRISAT's Farming Systems Research (FSR) Program. Initially, different weed management systems were evaluated in small plots. Recently emphasis has been placed on evaluating promising weed management systems suited to improved cropping systems for deep Vertisols on an operational scale. These experiments were conducted in the Vertisol watersheds in larger, replicated plots. To determine the feasibility and productivity of different weed management systems under different cropping systems on a year-round basis, we superimposed different weed management systems on other improved technology components developed by FSR subprograms. Weed management systems included were hand weeding (2 hand weedings in rainy season and 1 in postrainy season), herbicide (with 1 later hand weeding), smother crop (cowpea and mung) with weed-free and weedy controls (Fig. 28).

In sequential maize-chickpea, S1 Atrazine at 1.5 kg/ha before plants emerge gave excellent weed control and the herbicide-based system outyielded all other weeding systems, including weed-free. Two smother crops, mung and cowpea, seemed to compete with maize and reduced its yields but smother-crop yields compensated for maize's loss.

In general, yield of chickpea planted after maize harvest was poor because of continuously

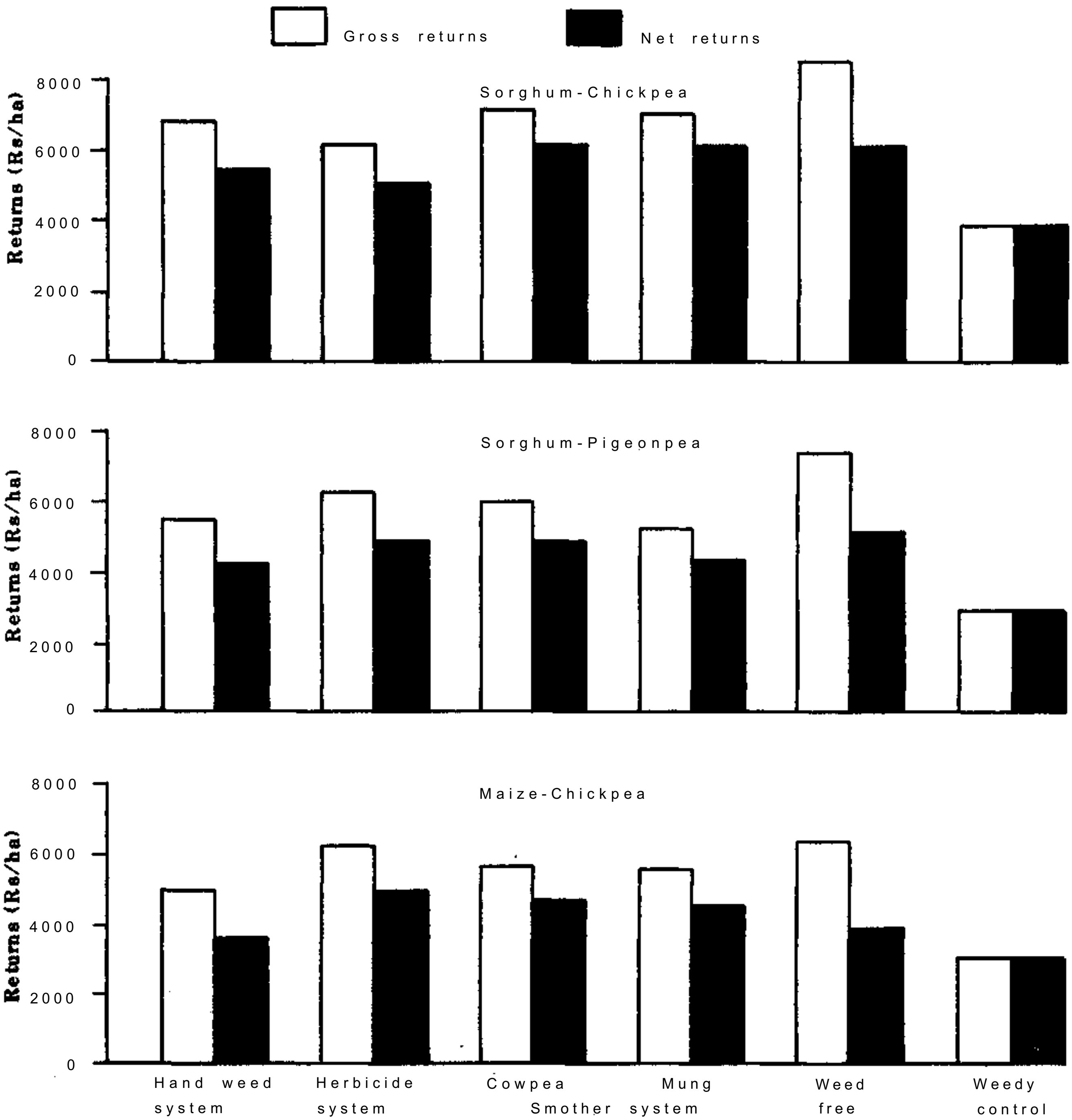
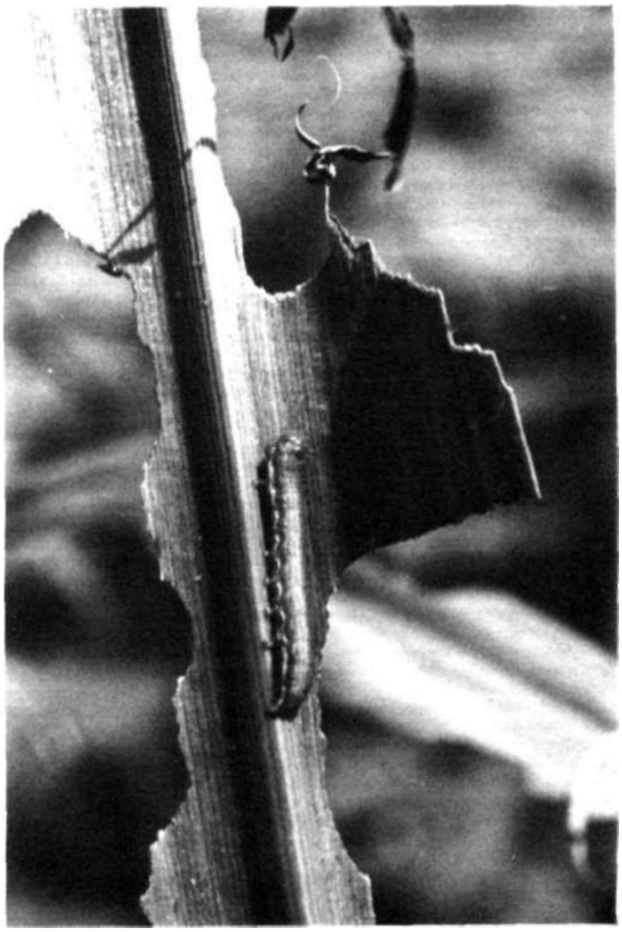


Figure 28. Effect of different weed management systems on economics of sorghum-chickpea zero tillage sequential cropping system, sorghum/pigeonpea intercrop system, and maize-chickpea sequential cropping system ICRISAT Center, 1981/82.

wet soil. Chickpea lost up to 40% of its yield to weeds. Maximum net returns were from the herbicide system followed closely by smother crop systems (Fig. 28). Monetary returns from the hand weeding system, smother crop, and herbicide system were, respectively, about 120, 155, and 165% more than from the weedy controls, confirming earlier findings that herbicide systems are economically feasible on deep Vertisols in high rainfall areas where timely manual or mechanical operations may not be possible. Smother cropping also seemed feasible on broadbeds as the smother crops could be planted easily between rows of maize with a bullock-drawn planter.



Defoliation in pearl millet caused by the armyworm **Mythimna separata.** *This pest, once extensive at ICRISAT Center, has been receding over the past 3 years. Populations recorded in light traps confirm observations of the crop scientists.*

Intercropping: sorghum/pigeonpea. Fluchloralin at 1.5 kg a.i/ha applied before plants emerge was particularly effective on grassy weeds but caused some phytotoxic symptoms on sorghum. Grain yields were highest in weed-free plots. Herbicide and smother-crop systems gave similar yields. Yield losses due to weeds were 50% in sorghum and 80% in pigeonpea. Cowpea as a smother crop competed severely with pigeonpea, reducing yields up to 65%. Net returns from herbicide and smother (mung) crop systems were almost the same (97%) as that from the weed-free system (Fig.28). Net returns from the weedy control were only about 60%) those from the weed-free system.

Sequential cropping:sorghum-chickpea. Table 33 summarizes results from the sorghum-chickpea sequential double crop. Herbicide used on sorghum was propazine (1.5 kg a.i/ha) followed by ametryne (0.75 kg a.i/ha) both before chickpea emerged during the postrainy season. After sorghum harvest, chickpea was planted with zero tillage directly into sorghum stubble. Paraquat was sprayed to prevent sorghum from resprouting. Chickpea established well under zero tillage.

The weed-free system gave the highest chickpea yield followed closely by the herbicide system. Net returns from weed-free and smother

Table 33. Effect of different weed management systems on the yields (kg/ha) of sorghum-chickpea cropping systems.

	Rainy		
Treatments	Sorghum	Smother crop	Postrainy
Hand weed system	4160		930
Herbicide system	3770		820
Smother system			
Cowpea	3790	270	880
Mung	4030	40	990
Weed free	4730		1250
Weedy check	1930		670
SE	±275		±178

systems were similar, followed by returns from hand-weed and herbicide systems (Fig. 28).

Light Traps

We record the numbers of many insect species caught in three light traps operated nightly on our research farm at ICRISAT Center. Continuous trapping records since 1974 give us valuable information concerning the seasonal incidence of some of the crops' major insect pests (Table 34). The trap data confirm our observations that in our pulse crops pest problems, particularly of *H. armigera,* were more severe than usual in 1982 and that *Chilo partellus* was relatively uncommon on sorghum. The data confirm that populations of *Mythimna separata,* the Asian armyworm that defoliated much of our millet and sorghum earlier, have been lower the last 3 years.

The light-trap data also show a substantial increase in *Spodoptera litura* the last 2 years; formerly regarded as a major pest only on tobacco, it has expanded its host range and is now a major pest of cotton and groundnuts in several areas of southern India. Before 1980 it was not important on groundnut crops at ICRISAT Center but in 1981 and 1982 it heavily infested our groundnuts, both in the rainy and postrainy seasons. It is not easily controlled with pesticides.

We now receive data from light traps at 11 centers in India, a network operated by cooperators in the national programs. We hope that data from traps will enable us to determine seasonal incidence and movement, if any, of *H. armigera* across geographical areas. We also hope to eventually correlate the data with climatic and crop data so we can determine factors involved in population fluctuations. Patterns of catches differ at each center, with maximum catches later in Gwalior and Hissar in northern India, where cold winters limit populations from November to February.

We have supplemented the light trap network. with pheromone traps that monitor *H. armigera* moths. Our pulse entomologists organized this network, which now covers 26 centers in India, and will soon be spread into Pakistan and Bangladesh.

Pest-parasitoid Surveys

We continued to survey the pest-parasitoid complex on chickpeas by collecting pest larvae from farmers' fields and rearing them in our laboratory to determine parasite incidence. Most of our 1982 observations were on *H. armigera* lar-

Table 34. Catches of some important insect pests in a light trap on a Vertisol watershed, ICRISAT Center, 1977-82.

	Catches, June-May				
	1977/78	1978/79	1979/80	1980/81	1981/82
Legume borers					
Adisura marginalis	327	990	343	268	2835
Adisura stigmatica	1618	4212	1713	1586	7196
Etiella zinckenella	'6542	6650	5385	7549	13002
Heliothis armigera	16207	10633	18019	7653	37524
Maruca testulalis	2872	1877	995	1092	1000
Cereal pests					
Chilo partellus	3210	4088	17882	18635	4154
Mythimna separata	3649	2097	208	280	186
Groundnut pest					
Spodoptera litura	3328	4406	3401	10491	7708

vae, of which more than 4000 were collected; 49.5% in the first two instars were parasitized hy the hymenopteran *Campoletis chlorideae.* Of the larger larvae, 21% were parasitized by the dipteran *Carcelia illota.* A few other parasites, including *Microchelonus curvimaculatus, Palexorista* sp, *Sturmiopsis inferens,* and *Goniophlhalmus halli* also were collected.

Predator Studies

Using field cages, we studied *Delta* spp the wasps that are common predators of *H. armigera,* and other lepidopteran larvae this year in our fields. The wasps collect large larvae from the plants and put them in mud nests to be eaten by wasp larvae. Three species of *Delta* were studied: *D. conoideum* and *D. campaniforme esuriens,* both recorded earlier as predators of *Heliothis,* and *D. pyriforme,* which we recorded as a predator of *Heliothis* for the first time this year.

Our studies indicated that although the predators can each destroy many pest larvae, several factors limit their populations and, hence, their effectiveness. They require a convenient source of water and suitable resting sites, which are not available in most fields.

We recorded ants destroying many of the wasp nests, and a high proportion of wasp larvae were parasitized by *Chrysis fuscipennis, C. quaerita* and *Stilhum cyanurum.* Those constraints appear to make it impracticable to augment populations of these useful predators.

Biological control: predatory wasps prey on damaging insects such as Heliothis armigera, *collecting their larvae from the plants and putting them in mud nests for wasp larvae to feed on. These predators may be of limited use in farmers' fields, because they require an assured source of water and convenient resting sites.*

Systems Analysis and Modeling

Crop-weather Modeling: Sorghum and Pearl Millet

Crop-weather models, physiologically based and driven by environmental factors, are useful in evaluating effects of different production factors—singly or in combination through a systems approach. Such models are valuable research tools to examine possible consequences of introducing new technologies under a range of agroclimatic situations. To validate and improve the sorghum simulation model (SORGF), we initiated experiments after the 1979 rainy season at ICRISAT Center and nine other SAT locations in collaboration with the national research institutions. Simulating sorghum growth and development with this model showed that the model needs to be revised (ICRISAT Annual Report 1979/1980), and revisions are being carried out.

Experiments were initiated from the 1981 rainy season to collect standard data sets for developing a model to simulate pear) millet growth and development.

Sorghum Simulation Model (SORGF)

Continuous revisions, based on physical and physiological data collected from the multilocation trials during 1979-81, were carried out for several subroutines of the model in 1982 (Huda et al. 1982).

Subroutines Revised

Light interception. In SORGF, the quantum flux density (PAR) in Einsteins/m^2 per day is estimated from the energy flux density (RS) in cal/cm^2 per day as

$$PAR = RS\ (0.121)$$

Field measurements of PAR and RS at ICRISAT Center led us to alter the constant relating PAR to solar radiation (RS). In the revised version, PAR is calculated as 0.09 times RS.

Light transmission is calculated from the relationship between extinction coefficient and maximum light transmission with information on row spacing and LAI. The functions for estimating extinction coefficient and maximum light transmission were revised with appropriate functions derived from field data.

Phenology. To determine three stages of sorghum development, we developed new algorithms based on day-length and temperature effects. The stages are:

GS1 = The time from emergence to panicle initiation.

GS2 = The time from panicle initiation to anthesis.

GS3 = The time from anthesis to physiological maturity.

The algorithm for describing the relationship between day length at emergence (DAYEM) and growing degree days (GDD) effects on GS1 was derived as follows:

$$GDD = 370 + 400^{*}\ (DAYEM - 13.6) \quad \text{if } DAYEM \geq 13.6 \text{ hr}$$

$$GDD = 370 \quad \text{if } DAYEM \leq 13.6 \text{ hr}$$

The algorithm for describing DAYEM and GDD effects on GS2, similarly derived as that of GS1, is:

$$GDD = 650 + 120^{*}\ (DAYEM - 13.6) \quad \text{if } DAYEM \geq 13.6 \text{ hr.}$$

$$GDD = 650 \quad \text{if } DAYEM \leq 13.6 \text{ hr.}$$

For GS3, the following algorithms are used to account for temperature effects in GDD computation for GS3.

If T = mean temperature in GS3

$$GDD = T - 7 \quad \text{when } T \leq 27°C$$

$$GDD = (54 - T) - 7 \quad \text{when } T \geq 27°C.$$

Dry-matter accumulation and partitioning. A simpler relationship for calculating daily dry-matter production from intercepted PAR was developed. From measured data over several growing seasons, we computed that, potentially 3.0 g of total dry matter can be produced for each MJ of PAR absorbed without drought or temperature stress. From the computed value of daily potential dry matter production, actual dry-matter increase is estimated as a function of temperature and drought stress.

We studied partitioning total dry matter (TDM) to leaf, culm, head, and grain by using data collected at weekly intervals from 27 field studies at ICRISAT Center. TDM at anthesis and maturity did not differ significantly between hybrids. The percentages of TDM partitioned to leaf did not differ significantly between hybrids and varieties. The proportion of TDM accumulated in the culm was significantly higher in varieties than in hybrids, at both anthesis and maturity. Dry matter partitioned to grain as a percentage of TDM was higher in hybrids (0.45) than varieties (0.32).

The data confirm that hybrids translocate dry matter to grain more efficiently than varieties.

Soil water. By revising the procedure for estimating evaporation from a bare soil surface (Eo), we improved soil water estimates. Incorporating a seepage subroutine to account for the water balance in different layers of soil, instead of a whole soil profile procedure, gave reasonable estimates of soil water, especially for nonirrigated sorghum.

A layered model provided improved estimates of drought stress coefficients (DSCO) to account for drought stress on sorghum dry-matter production on a daily basis (Fig.29).

Leaf development. After full expansion of leaf 7, with each successive leaf (leaf 8, 9, 10, etc.) expansion, consecutive leaves in the lower canopy (leaf 2,

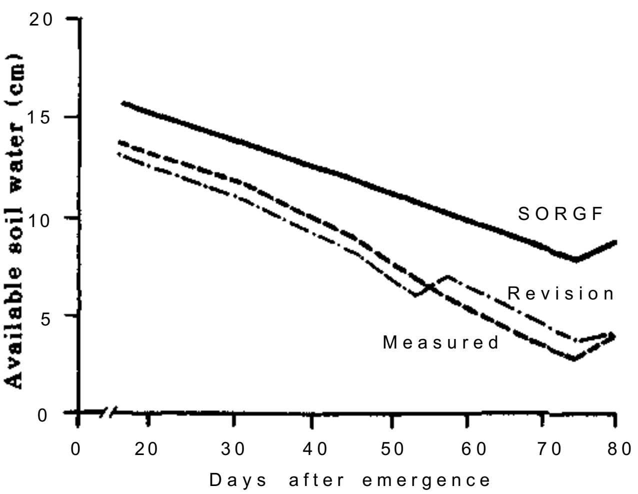


Figure 29. Measured and simulated available soil water in a deep Vertisol under nonirrif ated sorghum.

3,4...) senesce. Lower-canopy leaf area at physiological maturity (PM) is 50% of leaf area at anthesis (AN).

Estimating leaf area. Leaf area of individual leaves is a model input: But measurements of leaf area usually are not available at most locations, so we estimated leaf area from leaf length and maximum width and from only leaf length. We also estimated area for individual leaves to ascertain variability in coefficients for each leaf. The coefficients differed among genotypes, environments, and individual leaves. Regression coefficients relating the product of leaf length and maximum width to leaf area for four genotypes grown at ICRISAT Center ranged from 0.67 to 0.71.

Experimental Results (1981/82)

Trials during the 1981 rainy season were conducted under the following conditions with selected genotypes (CSH-1, CSH-5, CSH-6, and SPV-351):

1. Alfisol with 85 mm of available water-holding capacity under high fertility (100 kg N, 60 kg P/ ha) and intensive plant protection.

2. Alfisol with 85 mm of available water-holding capacity under medium fertility (40 kg N, 20 kg P/ ha) and no plant protection.

3. Medium deep Vertisol with 165 mm of available water-holding capacity under high fertility (100 kg N, 60 kg P/ha) and intensive plant protection.

4. Deep Vertisol with 200 mm of available water-holding capacity with high fertility (100 kg N, 60 kg P/ha) and intensive plant protection.

Variations in phenology, leaf-area index, total dry matter, and grain yield for different genotypes are compared under the four experimental conditions. Standard data sets on soil, crop, weather, and microclimate were collected to test the revised SORGF model. Results of the experiments are described in detail in Agroclimatology progress report 8.

Rainfall during 1981 was above normal: 917 mm June to September compared with 624 mm normal. Higher rainfall helped all genotypes maintain increased green leaf area until they matured. SPV-351 maintained its LAI at nearly 3.0 at PM in both fields; CSH-1 and CSH-6 maintained higher LAI (2.5) at PM in Alfisol than in medium deep Vertisol. Both CSH-1 and CSH-6 had higher leaf area duration during grain filling in Alfisol than in Vertisol, and higher grain yield and total dry matter in Alfisol. For CSH-1 and CSH-6, the yield difference was nearly 1000 kg/ha (Table 35).

Total dry matter for SPV-351 was more than 2500 kg/ha in Alfisol, but it had a low harvest index and low grain yield. Grain yields were similar for all genotypes on medium deep and deep Vertisol.

Simulation Comparison

The revised algorithms discussed earlier were incorporated in SORGF. Simulation results of several components of the model and the yield simulations were compared with observed data. Examples from testing some of the revised algorithms with the data obtained from 1981/82 experiments (which were not used for model revision) are given.

Emergence. In SORGF, emergence is simulated when 70 heat units above 7^{0}C base temperature accumulate after sowing, provided available soil water for the entire profile exceeds 10%.

The results of emergence computations were compared with data obtained from the 1981 rainy-season experiments at ICRISAT Center. Sorghum was dry sown (a recommended practice for Vertisols) on a deep Vertisol (10 June) and on a medium deep Vertisol (12 June). The available water-holding capacities of the deep Vertisols and medium deep Vertisols was 200 and 165 mm, respectively. At sowing, water available in the entire profile for the two fields was 65 and 29 mm, respectively (above 10% for the entire profile for both fields).

In SORGF, emergence was computed to occur within 4 days after sowing; however, the top 30-cm layer of each field contained no available water, so emergence in both fields was 22 June after 35 mm of rainfall 18 June. When the layered soil-water model (top 0-30 cm; and beyond 30 cm) was used, the emergence date for both fields was simulated as 21 June, 1 day earlier than actual.

Phenology. Computations of phenological events such as PI, AN, and PM were compared with 19 observations from 1981/82 experiments. With revisions in the phenology algorithms, the time from emergence to PI was computed within ±2 days compared with ±5 days with SORGF. Similarly the root mean square error (RMSE) in simulating time from emergence to maturity was reduced from ±15 days to ±4 days.

Table 35. Indicated sorghum grain yields (kg/ha), ICRISAT Center, 1981.

Genotype	Alfisol (RP-4)	Alfisol medium fertility pesticide free (RUS-3)	Medium deep Vertisol (BP-12)	Deep Vertisol (BW-3)
CSH-1	5580 ±153	3520 ±335	4440 ±48	4850 ±500
CSH-5	[a]	191Q ±206	—	4370 ±924
CSH-6	6270 ±255	3410 ±160	5000 ±169	5040 ±207
CSH-8-R		1610 ±264	—	4020 ±528
SPV-351	4580 ±483	2420 ±738	4460 ±404	4390 ±286

a. - denotes fields not included.

Grain yield. Improvements made in the model were tested with data sets obtained during 1981 at ICRISAT Center. Revisions in the model improved the coefficient of determination (R^2) by 35% (R^2 for SORGF = 0.48, revision = 0.83) for grain yields (N = 20). The root mean square error (RMSE) was reduced by the revision from 1423 kg/ha to 592 kg/ha.

We used pooled data (N = 59) over different seasons and genotypes from ICRISAT Center and other cooperating centers to do the grain yield simulation. The R^2 improved from 0.27 for SORGF to 0.74 for the revised model. The RMSE was reduced from 1479 kg/ha for SORGF to 591 kg/ha for the revised model.

Pearl Millet Modeling

Pearl millet was the next choice for extending our modeling efforts, and this work has begun in cooperation with the Pearl Millet Improvement Program at ICRISAT Center. To develop a growth and development model, we started experiments involving several genotypes and treatments (moisture, methods of planting, row spacing) in the 1981 rainy season. We are collecting standard data sets on crop, soil, and weather.

The framework of the sorghum model can be used with some modifications to produce a pearl millet growth model. Modifications include changing the individual leaf concept, as in SORGF, to leaf-area index. Developing and incorporating a tillering subroutine is important.

Hydrological Modeling and Simulation

We developed a runoff model based on the modified curve number technique developed by Hawkins in 1978 and on a soil-moisture accounting procedure. Our objective was to predict with reasonable accuracy the daily, monthly, and annual runoff volume for small agricultural watersheds. This model uses 1-day time intervals and needs these inputs: daily rainfall, open-pan evaporation, field capacity, wilting point of different soil layers, total soil depth, profile soil moisture at saturation, light interception coefficient, and minimum soil moisture for evaporation.

The main outputs are daily runoff volume and soil moisture. The model has two main parameters determined through calibration with an optimization procedure. Once the parameters are determined for a particular soil and land management treatment, they can be used in similar situations to predict runoff and soil moisture. The parameters also can be used to extend short periods of. record into long-term periods for the calibrated watersheds.

Figure 30 shows the flow chart of this model. The terms used in the chart are:

Dc = Parameter representing soil depth,
SC = Parameter representing soil surface condition,
SM1 = Initial soilmoisture of layer I,
SM2 = Initial soil moisture of layer II,
MI = Moisture at field capacity in layer I,
M2 = Moisture at field capacity in layer II,
M3 = Minimum moisture level for evaporation,
M4 = Moisture at wilting point in layer I,
M5 = Moisture at wilting point in layer II,
S max = Profile moisture at saturation,
P = Rainfall,
E_0 = Pan evaporation,
Q = runoff,
ß = Light interception coefficient,
E* = Losses by evaporation,
ET = Evapotranspiration,
SMT = Total soil moisture,
Q = Predicted runoff,
S = Retention parameter,
DM = Rainfall excess/deficit
K Kn = Starting and ending dates

At ICRISAT Center, we used hydrologic data from Vertisol watersheds with different land-management treatments to derive and test the model—and 2 years of data to calibrate the model, which we tested with data from the 3rd year.

The performance of the model in predicting runoff from three Vertisol watersheds (Table 36) shows it accurately predicting annual runoff.

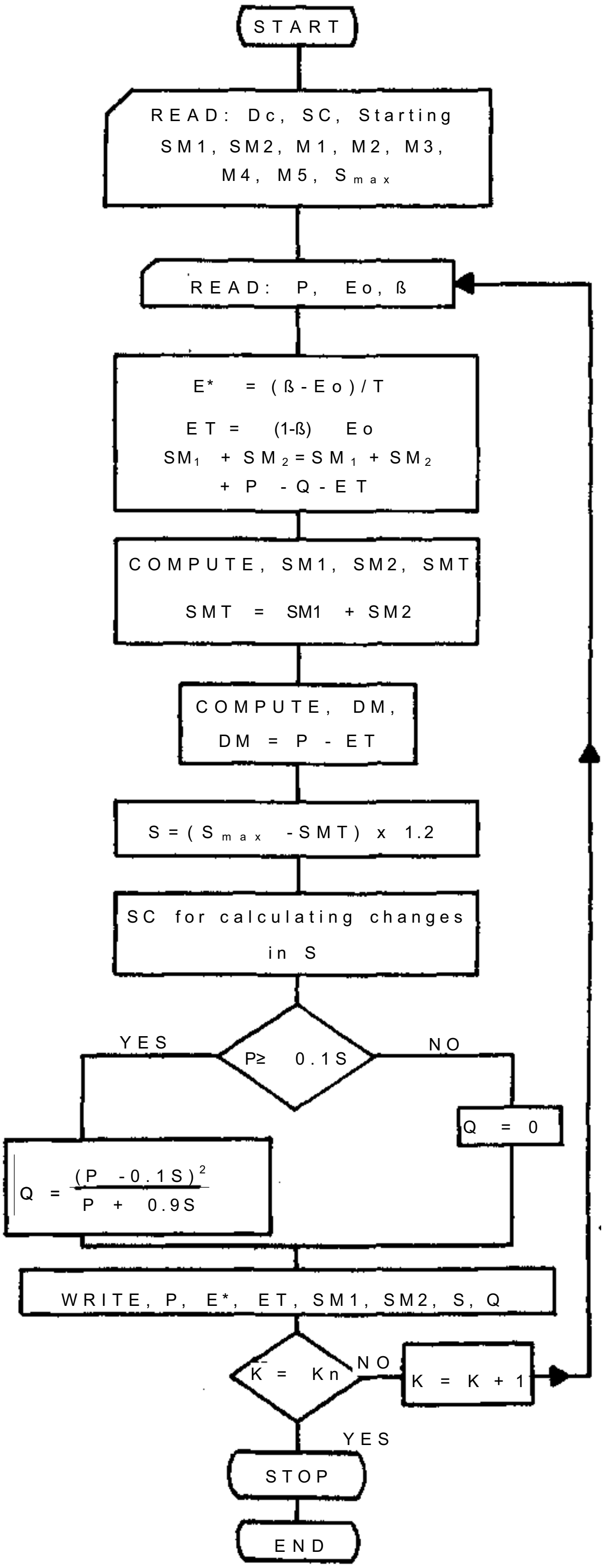


Figure 30. Flow chart of runoff model.

Predicted and measured runoffs of some big runoff events are compared in Table 37. It appears that the model can also satisfactorily predict individual, big runoff events.

On-farm Testing of the Vertisol Management Technology

During the past 9 years ICRISAT has been developing a management technology for deep black soils. The resulting package of practices is designed to make optimum use of both the rainy-season and postrainy-season growing periods. Results obtained at ICRISAT Center with this technology consistently showed increased production and profits over the traditional rainy-season fallow system. The package is described in detail in "Improving the management of India's deep black soils" (ICRISAT 1981) and the main components are summarized in the Economics section of this annual report.

In 1981 a joint project was initiated with Indian research institutions, the Andhra Pradesh (A.P.) Department of Agriculture, and 14 fanners to test the technology options under field conditions. Objectives of the project were to:

1. Verify whether the experience gained at ICRISAT could be replicated in farmers' fields.
2. Evaluate the performance of the technology options.
3. Test the ability of delivery systems to support demands of the improved technology options.
4. Study the technical and economic performance of the options in real-world conditions.

The selected fanners held a contiguous land area of 1S.4 ha at Taddanpally village, approximately 42 km northwest of ICRISAT Center. The area was chosen because it represented

Table 36. Measured and predicted seasonal runoff for three Vertisol watersheds at ICRISAT Center, 1976-80.

Treatment	Year	Rainfall (mm)	Measured runoff (mm)	Predicted runoff (mm)
Broadbed and furrow at 0.6% slope	1976	658	73	77
	1977	560	1	5
	1978	1091	269	264
	1979	616	73	76
	1980	728	116	112
Broadbed and furrow at 0.6% slope with field bunds	1977	566	0	0
	1978	1080	185	186
	1979	615	38	40
	1980	692	66	69
Broadbed and furrow at 0.4% slope	1976	644	51	46
	1977	562	0	1
	1978	1092	196	202

environmental conditions like those at ICRISAT Center. The project is described in detail in the Economics section of this annual report.

Farmers took loans to purchase the required inputs and performed most of the required labor. Unusual subsidies were kept to a minimum to allow the system to operate under normal village conditions, except that land surveys and the drainage layout were performed by soil conservation engineers from ICRISAT Center and the A.P. Department of Agriculture. The A.P. Department of Agriculture ensured that all inputs were available to farmers on time. And the farmers received intensive scientific counseling from both agencies. Farmers were given a thorough introduction to the theory and practices of the package and saw it in operation at ICRISAT Center.

Improved surface drainage is an important component of the package so land smoothing, drain construction, and developing of a broadbed and furrow system are important preliminary activities. These are described and average per hectare costs are presented in the Economics section of this report. The land development costs were surprisingly low (Rs.254/ha) for the Taddanpally test area.

After discussions with A.P. Department of Agriculture personnel and ICRISAT scientists, farmers chose appropriate cropping systems. This resulted in nine different systems, including one traditional cropping pattern. Crop yields were estimated with crop cuts taken by ICRISAT staff both in the test area and in neighboring fields. Crop combinations, yields, and profits are presented in Table 38. Yields of hybrid rainy-season sorghum as an intercrop in the watershed were about 2000 kg/ha; those of intercrop

Table 37. Comparison of predicted and measured big runoff events for two Vertisol watersheds, ICRISAT Center, 1978-80.

	Watershed BW1		Watershed BW2	
Year	Measured runoff (mm)	Predicted runoff (mm)	Measured runoff (mm)	Predicted runoff (mm)
1978	170	167	126	132
	50	39	38	37
1979	41	45	24	21
	23	20	13	15
1980	46	40	30	27
	16	14	34	35

Table 38. Economics of improved watershed-based technology options on deep black soils in Taddanpally village, Andhra Pradesh, 1981/82.[a]

Cropping system	Proportions grown (%)	Gross returns	Operational costs (Rs/ha)	Net returns	Yields (kg/ha) Cereals Grain	Cereals Fodder	Pulses/oilseeds/vegs. Grain	Pulses/oilseeds/vegs. Stalks
Improved watershed[b]								
Sorghum/pigeonpea intercrop	50	4930	1092	3838	1950	7200	460	1900
Maize/pigeonpea intercrop	6	4304	1395	2909	1640	3400	600	2200
Maize-safflower sequence	6	2301	1190	1111	1620	3500	50	-
Maize-chickpea sequence	5	5097	1831	3266	2290	5000	460	-
Mungbean-sorghum sequence	17	3352	1261	2091	590	1700	470	-
Mungbean-safflower sequence	3	3715	1321	2394	-	-	520 (mungbean)	-
							730 (safflower)	-
Mungbean-(sorghum/chickpea) sequence	4	4073	1495	2578	80	200	480 (mungbean)	-
							520 (chickpea)	-
Mungbean-chillies sequence	2	4625	1450	3175	-	-	520 (mungbean)	-
							500 (chillies)	-
Fallow chillies	7	2551	734	1817	-	-	410	-
Weighted averages	100	4242	1183	3059	-	-	-	-
Traditional farmer's fields								
Fallow-sorghum	90	2194	536	1658	670	1800	-	-
Fallow-chillies	4	3208	2036	1172	-	-	720	-
Mungbean-sorghum sequence	1	3964	1526	2438	970	2400	310	-
Sorghum/pigeonpea intercrop	5	1544	310	1234	550	2500	120	1600
Weighted averages	100	2220	595	1625	-	-	-	-

a. Prices used were actual realized or market prices just after harvest, as follows:

Grain	Rs/100 kg	Grain	Rs/100 kg	Fodder	Rs/100 kg
Hybrid sorghum	100	Pigeonpea	298	Hybrid sorghum	20.0
Postrainy season sorghum	220	safflower	300	Postrainy season sorghum	37.5
Maize	112	Chickpea (sold as seed)	450	Maize	10.0
Mungbean	300	Chillies	618	Pigeonpea stalks	10.0

b. Data refer to 14.48 ha of 15.42 ha watershed. Data not available from three plots.

Land smoothing at Taddanpally village: the cooperating farmers were asked to do this with their bullocks, and then install field drainage, as a part of the on-farm testing of ICRISAT's technology. At bottom, a traditional blade harrow is used for preparing the seedbed.

maize, 1600 kg/ha. Sole crop maize yielded 2300 kg/ha. The traditional postrainy-season sorghum yielded only 700 kg/ha after fallow. Economic analyses of the results are presented in the Economics section of this report. In general, production and profits were markedly higher under the improved system, with a 244% return on added expenditure.

Some unexpected agronomic problems arose, such as zinc deficiency on maize in the early stages of development, weeds (*Striga*), and heavy pod borer damage taking as much as two-thirds of a crop. Still the crops were generally good and results confirmed that on-farm yields could be similar to those from operational research on watersheds at ICRISAT Center.

Cropping Entomology Studies

We monitored populations of insect pests, their natural enemies, and farmers' pest control efforts on the crops grown at Taddanpally, particularly the sorghum/pigeonpea and maize/pigeonpea intercrops sown at the beginning of the rainy season. Although we recorded many shoot fly adults *(Atherigona soccata)* in traps, they

When farmers in ICRISAT's on-farm research at Taddanpally village tried nine crop combinations in 1982, the sorghumlpigeonpea intercrop was the most profitable (Rs. 3838/ha). Overall, the 14 farmers who participated in our watershed experiment earned Rs. 3059/ha, compared with the Rs. 1625 /ha average for other farmers in the village.

Taddanpally farmer using a knapsack sprayer to control **Heliothis armigera** *infestation on his pigeonpea crop. Effectiveness was limited because many farmers used such sprayers for the first time and also by poor quality insecticides.*

caused only a few deadhearts (<2%) in the sorghum.

Sown early in June, the sorghum had grown past the susceptible stage by August when we trapped 19 925 shoot flies in our fish meal-baited traps. Stem borers, *Chilo partellus,* were in less than 2% of the plants. Insect pests recorded in the sorghum heads, in too few numbers to cause substantial losses, included *Heliothis armigera: Eublemma silicuxlana, Euproctis subnutata* caterpillars, and *Calocoris angustatus* head bugs.

Insect pests caused even less damage in maize. Aphids stunted the growth of some plants, stem borers damaged a few, and *Heliothis armigera* larvae damaged some cobs. The farmers used no pesticide on sorghum or maize.

Pigeonpeas, which grew well with few insect pests in the vegetative stage, were heavily infested by *Heliothis armigera* larvae during flowering and podding stages in November. This pest fed on all crops grown at Taddanpally except chillies.

All the farmers used pesticides to control *H. armigera* infestations on pigeonpea; most farmers sprayed twice, mainly with DDT but some used endosulfan and quinalphos.

The pesticides were not effective because most farmers used inadequate dosages and sprayed too late. Some sprayed only after seeing the large, resistant larvae.

The cheap wettable DDT powder they used tended to settle in sprayer tanks. It is not easy for inexperienced operators to get good pesticide coverage on well-grown pigeonpeas with knapsack sprayers, and most of these farmers were spraying for the first time.

Table 39 shows damage the insects caused in

Table 39. Pigeonpea grain yields and pod damage by insect pests in farmers' fields at Taddanpally village, Andhra Pradesh, 1981/82.

Cropping system	Cultivar	No. of pods analyzed	% pod damage caused by Borer	Podfly	Hymenoptera	Total	Yield (kg/ha)
Sorghum/ pigeonpea intercrop	ICP-1	2950	46.5	26.5	0.9	68.0	677
	ST-1	5063	46.1	13.8	4.9	62.3	203
Maize/pigeonpea intercrop	ICP-1	7178	37.1	19.6	0.8	55.8	625
	ST-1	3625	51.0	14.7	1.7	62.7	574
Mean		45.2	18.6	2.1	62.2	520	
SE		±6.20	±4.58	±0.71	±4.37	±10.5	

four of the fields. More than 60% of the pods were damaged by insect pests, most by *H. armigera.* Although the yields were low, they were much better than yields of neighboring farmers' fields, who used no pesticide and lost almost all of their crops to *H. armigera.*

Some of the farmers sowed sorghum and chickpeas after the rains. The sorghum had few insect pests but aphids stunted some plants, and we found *H. armigera* larvae in some heads. Despite substantial parasitism of the young larvae by *Campoletis chlorideae, H.armigera* larvae severely infested the chickpeas. Farmers who used pesticides sprayed too late to prevent pod damage.

Farmers need training in the use of pesticides, and because tall pigeonpeas are not easy to spray with conventional sprayers, improved pesticide-application techniques are needed.

Expanding the On-farm Testing Program, 1982

At the first policy makers' seminar, at New Delhi in May 1981, on improving the management.of India's deep black soils, it was decided that state departments of agriculture should implement operational research projects to adapt and test suitable technologies for the black soil areas. ICRISAT agreed to provide knowledge on techniques it evolved to selected officers from the state governments and the Government of India.

Five groups of senior officers from the states of Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, Gujarat, and Andhra Pradesh and from the Ministry of Agriculture, Government of India, visited ICRISAT Center 2 to 5 days each between 31 August and 4 December 1981, to become acquainted with the technology and its performance.

Two 1-week workshops also were conducted for middle-level state officials responsible for guiding and supervising the operational research or pilot studies. In January-February 1982, a 2-week training program was organized for the extension officers and subject-matter specialists directly responsible for implementing the technology by working with farmers; about 100 visited ICRISAT Center. During the 694 man days the extension officers spent in training/ visitation programs, watersheds were jointly identified in different states for on-farm verification tests in the 1982/83 cropping season. The work began in February 1982 and rainy-season crops were planted in June-July. Verification of the black soils management technology now is progressing at 10 locations in four states.

Collaborating with Gujarat Agricultural University, we are evaluating suitable cropping systems for red soil areas of that State and, with

Tamil Nadu Department of Agriculture, we are identifying appropriate components of the technology for a selected watershed at Aruppukottai in Tamil Nadu.

ICRISAT is closely involved with the testing projects at Taddanpally and Sultanpur villages in Andhra Pradesh, in Bidar and Gulbarga districts of Karnataka, and in Raisen district in Madhya Pradesh (Fig. 31). Work was begun at those sites in February 1982. Details follow.

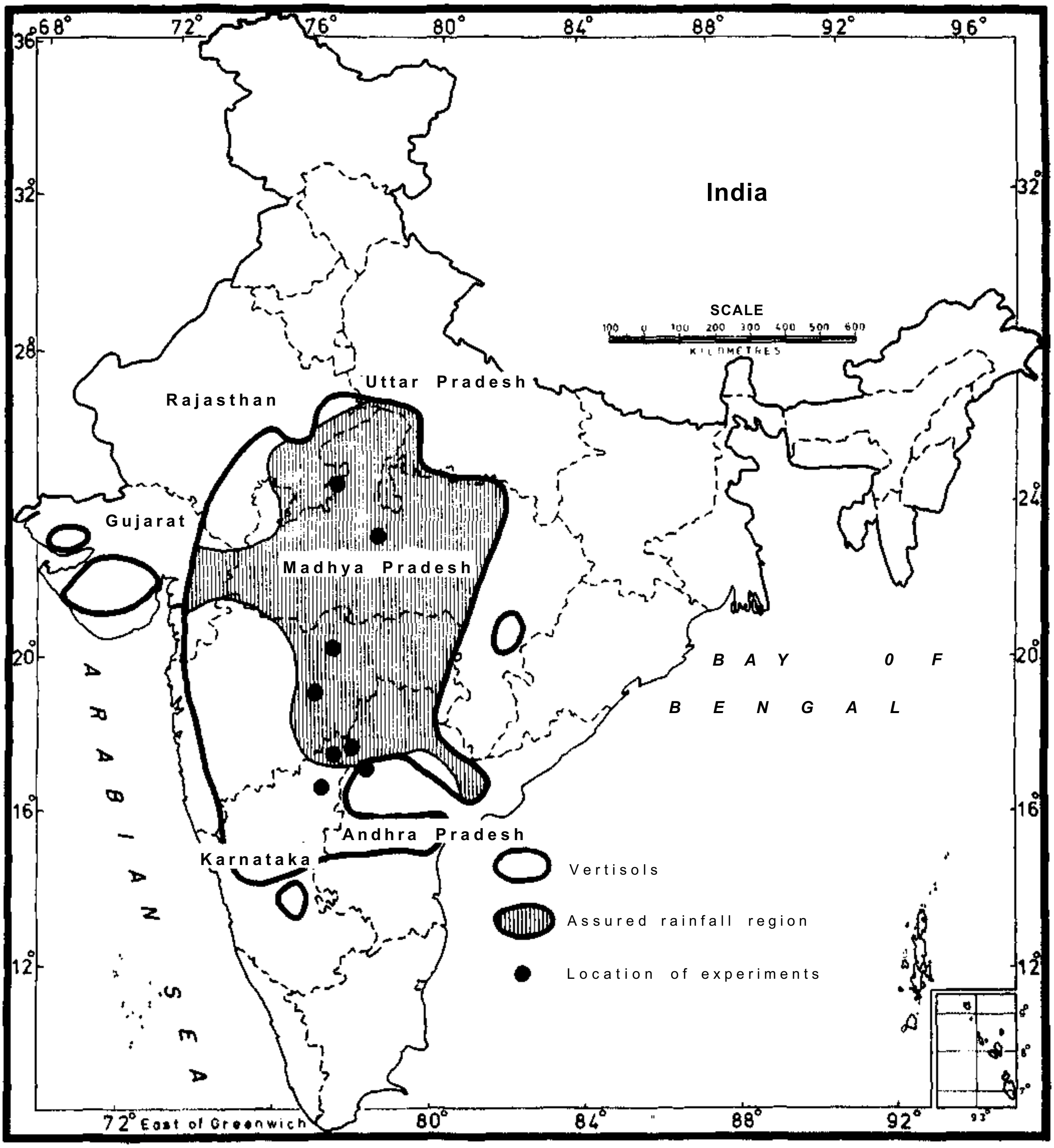


Figure 31. ICRISAT on-farm experiments in the deep-Vertisol, assured-rainfall regions of the Indian SAT.

Traditional implements were used to perform a variety of functions in the Taddanpally experiment. Here seed is covered with a blade harrow after broadcasting. At bottom, an ICRISAT research technician discusses implements with a farmer. The weeled tool carrier is seen in the background.

Andhra Pradesh

Medak district, Taddanpally, and Sultanpur villages. This project was expanded to include 25 farmers—as against the earlier 14—and the land area increased from 15 to 35.34 ha. Land was smoothed with a buck scraper; all other operations used a wheeled tool carrier.

Long-term average annual precipitation here (about 800 mm per year) does not differ significantly from that at ICRISAT Center.

Karnataka

Gulbarga district, Farhatabad village. Total project area is 16.5 ha, owned by two farmers. Postharvest plowing was by tractor and wheeled tool carrier; land smoothing, with a buck scraper. All other operations were by wheeled tool carrier.

Bidar district, Andhura village. This project—the smallest—involves one farmer who owns 8 ha. Most of the land preparation here was with the wheeled tool carrier.

The Farhatabad village site lies just outside the area of reliable rainfall (750 mm), while Andhura village is just inside the area.

Madhya Pradesh

Raisen district, Begumganj town. The project here includes 10 farmers and 25.2 ha. Raisen district has many tractors, so most of the land development was with tractors; 50% of the land smoothing was performed with locally-made, bullock-drawn scrapers, and about 50% of the bed formation was with wheeled tool carriers.

Average annual precipitation in Begumganj is around 1300 mm, about 500 mm more than at ICRISAT Center. All test locations are on deep black soils.

Routine Soils Laboratory

Soil tests in our laboratory totaled 76,122 in 1981. Analyses of soil available-N, as assessed by the alkaline permanganate method, have been reduced and soil mineral-N (nitrate and ammonium-N) increased.

Looking Ahead

Considerable progress has been made in refining methodologies to quantify moisture availability. The dependability of precipitation is the basis of our delineation of promising areas for double cropping and for dry-seeding ahead of the monsoons) in the deep Vertisol areas of India. Thus, the refined methodologies have contributed substantially to predictions for the deep Vertisols which have great potential for increases in food production.

Resource evaluation. We have initiated studies on principal-component analysis to identify clusters of locations with similar climatic profiles. And we will continue to emphasize climate evaluations for different crops and regions. The National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) are preparing much more accurate descriptions of India's soil resources. They and ICRISAT are jointly identifying the major benchmark soils (Vertisols and associated soils)—to focus technology transfer to the most appropriate soil and agroclimatic zones.

Detailed studies on the use of light, water, and nutrients by different genotypes, crops, and cropping systems (and their interactions) will continue to help us understand and evaluate the resource base, and to determine how it may be used in developing improved technologies.

We will continue our physiological studies to understand factors contributing to efficiency of light-energy conversion into dry matter in groundnut intercropping systems, especially groundnut/pearl millet or groundnut/pigeonpea intercrops.

We will investigate reasons for groundnuts responding positively to early drought stress, and we will continue our field investigations on temperature-yield relationships.

To establish patterns of competition and possible yield advantages under low moisture and/or low nutrient supply, we will increase emphasis on interactions between moisture and nutrients and initiate detailed experiments to study intercropped pigeonpea performances with different intensities and durations of cereal competition. We will strengthen our studies of yield stability and genotype evaluation in sorghum/cowpea and sorghum/pigeonpea intercropping systems, and disease studies—the last in cooperation with ICRISAT pulse pathologists.

We will continue to emphasize research on the behavior of nitrogen in the soil-plant system. Studies of nitrogen-fertilizer use will be extended to define more closely the conditions that promote efficient use of nitrogen by various cereal crops. Particularly important in this work are soil characteristics, agroclimate, and seasonal weather. We will intensify work on the extent to which leguminous crops biologically fix N; because such N is incorporated into organic matter, and because we need to investigate the usefulness of organic residues to SAT farmers, we are initiating new work on the turnover of organic C and N in soil.

We hope to characterize phosphorus's behavior in various crop-soil combinations. During 1983 we will begin two new studies: the availability of native soil phosphorus in the two major soils at ICRISAT Center (Alfisols and Vertisols), and how efficiently pigeonpeas use phosphorus.

For both nitrogen and phosphorus, increasing attention will be given to the behavior of nutrients in the soil. High priority factors are the effects of soil characteristics and seasonal moisture on nutrient x soil interactions.

On-station research. We will continue to focus on watershed-based resource development and management. Soil-crust management in Alfisols, managing soil cracking in Vertisols, and infiltration-control research in general will be emphasized, and we will continue evaluating cropping systems for deep, medium deep, and shallow black soils, and for Alfisols under low and medium fertility.

Soil management, particularly effects of different tillage methods, is receiving increasing attention as a way to manipulate water use, reduce soil erosion, increase yields, and control weeds.

We will monitor the on-farm performance of wheeled tool carriers—three manufacturers' models are now in use—to ensure quality and to provide feedback from users to manufacturers. This will also help us in modifying and designing farm implements.

We and the groundnut microbiologists will collaborate on designing a rhizobia applicator with a carrier suspended in water in equipment that can be attached to machinery farmers now use.

Studies that seek to exploit the natural competitiveness of crops or cropping systems will receive greater emphasis. Herbicide use for specific situations, such as rainy-season cropping on deep Vertisols, will also continue to be explored.

Weed research will be strengthened to develop management techniques for difficult-to-control weeds like *Cyperus rotundus* and *Cynodon dactylon.*

Modeling. To improve the sorghum model for assessing sorghum production potentials in drought affected areas and regions with poor soil fertility, we will continue investigating drought and nutrient stresses. Efforts to collect standard data sets to develop and validate a pearl millet-simulation model will be continued.

The two hydrologic models we now have available (RUNMOD and curve number technique) will be used for decision making under various management situations.

We will continue to use modeling as a tool to investigate aspects of optimizing machinery usage.

On-farm testing of promising technologies. Results of the first year's trials in farmers' fields were promising: they indicated that results on-station could be duplicated on farmers' fields. Policy problems that arise as the technology is extended to larger areas will need to be studied.

We expect successful testing of weed management systems on an operational scale at ICRISAT Center will lead to a system suitable for

The seedlfertilizer application machine at work on a wheeled tool carrier at the ICRISAT Center. ICRISAT's future plans include monitoring the on-farm performance of these carriers—three manufacturers' models are now in use—to ensure quality and to provide feedback from users to manufacturers. This work will also provide information to be used in modifying and designing new farm implements.

on-farm testing. We will initiate studies of on-farm weed problems.

ICRISAT is currently cooperating closely with three of the four state governments which have test projects under way; several other states are also interested in testing this technology. We may need to continue and intensify our participation in such projects, which give us direct contact with farmers and help increase our awareness of problems they face. This effort will also enable us to modify our package for various crop-environment combinations.

Publications

Institute Publications

THIERSTEIN, G.E. 1982. The animal-drawn wheeled tool carrier. Information Bulletin No. 8.

Journal Articles

AHMED, S., and RAO, M.R. 1982. Performance of maize-soybean intercrop combination in the tropics. Results of a multilocation study. Field Crops Research 5(2): 147-162.

BANSAL, R.K., and THIERSTEIN, G.E. 1982. Animal drawn multi-purpose tool carriers. Autumn Agricultural Mechanization in Asia, Africa and Latin America 13(4):27-36.

DAV1ES, E.L.P., and SHETTY.S.V.R. 1981. Herbicide research on groundnut and sorghum under farmer conditions in the Indian semi-arid tropics. Tropical Pest Management 27(4):472-479.

GREGORY, P., and REDDY, M.S. 1982. Root growth in an intercrop of pearl millet/groundnut. Field Crops Research 5:241-252.

REDDY, M.S., and WILLEY, R.W. 1982. Improved cropping systems for the deep Vertisols of the Indian semi-arid tropics. Experimental Agriculture 18:277-287.

SAHRAWAT, K.L. 1980. A rapid nondigestion method for determination of potassium in plant tissue. Commununications in Soil Science and Plant Analysis 11:753-758.

SAHRAWAT, K.L., and BURFORD, J.R. 1982. Modification of the alkaline permanganate method for assessing the availability of soil nitrogen in upland soils. Soil Science 133:53-57.

SHETTY, S.V.R., SIVAKUMAR, M.V.K., and RAM, S.A. 1982. Studies on the effect of shading on the growth of some common weeds of the semi-arid tropics. Agronomy Journal 74:1023-1028.

Conference Papers

BANSAL, R.K., and THIERSTEIN, G.E. 1982. Design and development of planter-cum-fertilizer drill for dryland crops. Presented at the XIX Annual Convention of Indian Society of Agricultural Engineers, 15-17 Feb 1982, Udaipur, India.

GOSWAMI, N.N., and SAHRAWAT, K.L. 1982. Nutrient transformations in soils - Macronutrients. Pages 123-145 in Review of soil research in India, Part I: Transactions of the 12th International Congress of Soil Science, Vol. 1; 8-16 Feb 1982, New Delhi, India.

HUDA, A.K.S., SIVAKUMAR, M.V.K., VIRMANI, S.M., DUGAS, W.A., and ARKIN, G.F. 1981. Evaluation of a dynamic grain sorghum growth simulation model (SORGF) in the semi-arid tropics. Presented at the ASA, CSSA, and SSSA Annual Meetings, 29 Nov-4 Dec 1981, Atlanta, Georgia, USA.

HUDA, A.K.S., SIVAKUMAR, M.V.K., VIRMANI, S.M., SEKARAN, J.G., and SARDAR SINGH. 1982. Role of simulation models in yield predictions - ICRISAT experience in modeling sorghum growth and development. Presented at the IRAT-ICRISAT Workshop on Water Management and Crop Production, 3-6 May 1982, IRAT, Montpellier, France.

HUDA, A.K.S., SIVAKUMAR, M.V.K., VIRMANI, S.M., SEETHARAMA, N., SARDAR SINGH, and SEKARAN, J.G. 1982. Environmental factors and modeling sorghum growth and development. Presented at the ICRISAT/WMO Symposium/Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics, 15-19 Nov 1982, ICRISAT, Patancheru, India.

HUDA, A.K.S., SIVAKUMAR, M.V.K., ALAGARSWAMY, G., VIRMANI, S.M., and VANDERLIP, R.L. 1982. Problems and prospects in modeling pearl millet growth and development. Presented at the ICRISAT/WMO Symposium/Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics. 15-19 Nov 1982, ICRISAT, Patancheru, India.

HUDA, A.K.S., SIVAKUMAR, M.V.K., ALAGARSWAMY, G., and VIRMANI, S.M. 1982. Preliminary investigations on modeling pearl millet growth and development in the semi-arid regions. Presented at the ASA, CSSA, and SSSA Annual Meetings, 28 Nov-3 Dec 1982, Anaheim, California, USA.

KANEMASU, E.T., PIARA SINGH, and CHOUDHRY, U.N. 1982. Water use and water use efficiency of pearl millet *(Pennisetum americanum* (L.) and sorghum *(Sorghum bicolor* L. Moench). Presented at the ICRISAT-WMO Symposium/ Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics, 15-19 Nov 1982, ICRISAT, Patancheru, India.

MIRANDA, S.M., PATHAK, P., and SRIVASTAVA, K.L. 1982. Runoff management on small agriculutral watersheds: the ICRISAT experience. Presented at the National Seminar on A Decade of Dryland Agriculture Research in India and Thrust in the Eighties, AICRPDA, 19-21 Jan 1982, Hyderabad, India.

MIRANDA, S.M., PATHAK, P., and SRIVASTAVA, K.L. 1982. Report on the ICAR-ICRISAT cooperative FS1 and FS2 research project at ICRISAT. Presented at the Working Group Meeting, May 1982, Hyderabad, India.

MORAGHAN, J.T., REGO, T.J., and SARDAR SINGH. 1981. Aspects of nitrogen fertilization on sorghum production. Page 743 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

PATHAK, P., and MIRANDA, S.M. 1982. Sediment flow and its measurement from small agricultural watersheds. Presented at the XIX Annual Convention of Indian Society of Agricultural Engineers, 15-17 Feb 1982, Udaipur, India.

RAO, A.N., and SHETTY, S.V.R. 1981. Investigation on weed suppressing ability of smother cropping systems in relation to canopy development and light interception. Pages 357-364 *in* Proceedings of the 8th Asian Pacific Weed Science Society Conference, 22-29 Nov 1981, Bangalore, India.

RAO, J.K., SAHRAWAT, K.L., and BURFORD, J.R. 1982. Diagnosis of iron deficiency in groundnut. Page 527 *in* Proceedings of the Ninth International Plant Nutrition Colloquium, vol. 2, 22-27 Aug 1982, Commonwealth Agricultural Bureaux, Warwick University, UK.

RAO, K.V., REGO, T.J., SAHRAWAT, K.L., and BURFORD, J.R. 1982. Responsiveness of pigeonpea (*Cajanus cajan* L. Millsp.) to fertilizer phosphorus. Page 74 *in* Abstracts: Transactions of the 12th International Congress of Soil Science, vol. 6; 8-16 Feb 1982, New Delhi, India.

RAO, M.R. 1982. Improved cropping systems for increased and stable yields on Vertisols and Alfisols of semi-arid tropical India. Presented at the 9th Annual Marketing Conference of Indian Farmers Fertilizer Cooperative Limited, 10-12 Feb 1982, Trivandrum, India.

RAO, M.R., REDDY, M.S., and WILLEY, R.W. 1982. Improved rainfed cropping systems for Vertisols and Alfisols of semi-arid tropical India. Presented at the National Seminar on A Decade of Dryland Agricultural Research in India and Thrust in the Eighties, AICRPDA, 18-21 Jan 1982, Hyderabad, India.

REGO, T.J., MORAGHAN, J.T., and SARDAR SINGH. 1982. Some aspects of soil nitrogen relating to double cropping of a deep Vertisol in the SAT. Page 116 m Abstracts: Transactions of the 12th International Congress of Soil Science, vol. 6; 8-16 Feb 1982, New Delhi, India.

REDDY, M.S., REGO, T.J., BURFORD, J.R., and WILLEY, R.W. 1982. Fertilizer management in multiple cropping systems with particular reference to ICRISAT's experience. Presented at the FAO-Expert Consultation on Fertilizer Use under Multiple Cropping Systems, 1-6 Feb 1982, New Delhi, India.

SAHRAWAT, K.L. 1982. Effects of retardation of nitrification on composition and yield of crops. Pages 570-575 *in* Proceedings of the Ninth International Plant Nutrition Colloquium, vol. 2; 22-27 Aug 1982, Commonwealth Agricultural Bureaux, Warwick University, UK.

SEETHARAMA, N., WADE, L.J., PEACOCK, J.M., VERMA, P.K., REGO, T.J., and SARDAR SINGH. 1982. Effect of nitrogen and water stress on leaf area development in sorghum. Pages 595-600 *in* Proceedings of the Ninth International Plant Nutrition Colloquium, vol. 2; 22-27 Aug 1982, Commonwealth Agricultural Bureaux, Warwick University, UK.

SEETHARAMA, N., SIVAKUMAR, M.V.K., BIDINGER, F.R., SARDAR SINGH., MAITI, R.K., REDDY, B.V.S., PEACOCK, J.M., REDDY, S.J., MAHALAKSHMI, V., SACHAN, R.C., SHIV RAJ, K., MURTY, S.R.K., NARAYANA, A., KANANGARA, T., DURBY, R.C., and SIMPSON, G.M. 1981. Problems and prospects for increasing yield under drought; criticism and synthesis with sorghum. Paper presented at the Symposium on Plant Physiology and Biochemistry in the 80's, 20-25 Nov 1981, IARI, New Delhi.

SHETTY, S.V.R. 1981. Some aspects of weed management in pigeonpea. Pages 137-145 *in* Proceedings, International Workshop on Pigeonpeas, vol. 1. ICRISAT, 15-19 Dec 1980, Patancheru, A.P., India.

SHETTY, S.V.R. 1982. Weed control in intercropping systems. Presented at the FAO Workshop on Weed Management Strategies for the Eighties, 6-10 Sept 1982, FAO, Rome, Italy.

SHETTY, S.V.R., and MOODY, K. 1982. Influence of alternate management techniques on weed growth and yields of mungbean planted after rice. Presented at the 13th Annual Conference of the Pest Control Council of the Philippines, 5-8 May 1982, Baguio city, Philippines.

SINGH, PIARA., GUNASEKERA, B.C.G., and SARDAR SINGH. 1982. Profile water dynamics in Alfisols and Vertisols in relation to root distribution. Presented at the IRAT-1CRISAT Workshop on Water Management and Crop Production, 3-6 May 1982, IRAT, Montpellier, France.

SINGHAL, O.P., and THIERSTEIN, G.E. Use of solar energy in post-harvest technology. Presented at the UNU-ICRISAT-NIN-CFTRI Workshop on Interfaces between Agriculture, Food Sciences and Nutrition. 10-12 Nov 1981, ICRISAT, Patancheru, A.P., India.

SIVAKUMAR, M.V.K. 1981. Crop modeling. Paper presented at the Symposium on Plant Physiology and Biochemistry in the 80's, 20-23 Nov 1981. IARI, New Delhi.

SIVAKUMAR, M.V.K., and REGO, T.J. 1982. Agroclimatic conditions of rainfed areas of India in relation to fertilizer use. Presented at the Fifth FAI Specialized Training Program on Management of Rainfed Areas, 20-23 Sept 1982, Fertilizer Association of India, New Delhi.

SIVAKUMAR, M.V.K., and VIRMANI, S.M. 1981. The physical environment. Pages 83-100 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT. India.

SIVAKUMAR, M.V.K., and VIRMANI, S.M. 1982. Agrometeorology—An aid to crop planning in drought prone areas. Presented at the Seminar-cum-Workshop on Planning for Dryland Agriculture in DPAP Areas, 27-29 May 1982, All India Coordinated Research Project for Dryland Agriculutre (AICRPDA), Hyderabad, India.

SIVAKUMAR, M.V.K., REGO, T.J., SARDAR SINGH., and VIRMANI, S.M. 1981. Response of pearl millet to nitrogen and moisture stress in a semi-arid environment. Presented at the ASA, CSSA and SSSA Annual Meetings, 29 Nov-4 Dec 1981, Atlanta, Georgia, USA.

SIVAKUMAR, M.V.K., HUDA, A.K.S., and VIRMANI, S.M. 1982. Physical environment of sorghum and millet growing areas in South Asia. Presented at the ICRISAT-WMO Symposium/Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics, 15-19 Nov 1982, ICRISAT, Patancheru, India.

SIVAKUMAR, M.V.K., WILLIAMS, J.H., SARDAR SINGH, and SAHRAWAT, K.L. 1982. Response of groundnut to moisture stress at different growth stages in a semi-arid environment. Presented at the ASA, CSSA, SSSA Annual Meetings, 28 Nov-3 Dec 1982, Anaheim, California, USA.

SIVAKUMAR, M.V.K., SACHAN, R.C., HUDA, A.K.S., SARDAR SINGH, SEETHARAMA, N., and VIRMANI, S.M. 1982. Crop response to available water and water requirements. Presented at the IRAT-ICRISAT Workshop on Water Management and Crop Production, 3-6 May 1982, IRAT, Montpettier, France.

SRIVASTAVA, K.L., MIRANDA, S.M., GUNASEKERA, B.C.G., and VIRMANI, S.M. 1982. Land and water management in rainfed farming systems. Presented at the IRAT-ICRISAT Workshop on Water Management and Crop Production, 3-6 May 1982, IRAT, Montpellier, France.

THIERSTEIN, G.E. 1982. The efficient use of power in dryland agriculture. Presented at the National Seminar on A Decade of Dryland Agriculture Research in India and Thrust in the Eighties, 18-21 Jan 1982, AICRPDA, Hyderabad, India.

THIERSTEIN, G.E., and REGO, T.J. 1982. The need for suitable implements for fertilizer application in multiple cropping systems with special reference to small farmers. Presented at the FAO-expert Consultation on Fertilizer Use under Multiple Cropping Systems; 1-6 Feb 1982, New Delhi, India.

VIRMANI, S.M. 1982. Increased and stabilized production of sorghum/ millet based farming systems in the semi-arid tropics: Role of agroclimatic studies. Presented at the ICRISAT-WMO Symposium/ Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics, 15-19 Nov 1982, ICRISAT, Patancheru, India.

VIRMANI, S.M., and SIVAKUMAR, M.V.K. 1982. Studies on rainfall climatology, evaporative demand and climatic water balance conducted at ICRISAT. Presented at the IRAT-ICRISAT Workshop on Water Management and Crop Production, 3-6 May 1982, IRAT, Montpellier, France.

VIRMANI, S.M., BURFORD, J.R., and SAHRAWAT, K.L. 1982. Improved management systems for Vertisols in India. Presented at the Fifth International Soil Classification Workshop, 1-11 Nov 1982, Khartoum, Sudan.

VIRMANI, S.M., HUDA, A.K.S., SIVAKUMAR, M.V.K., and SEETHARAMA, N. 1982. Prediction of leaf area in grain sorghum. Presented at the ASA, CSSA, SSSA Annual Meetings, 28 Nov-3 Dec 1982, Anaheim, California, USA.

VIRMANI, S.M., SAHRAWAT, K.L., and BURFORD, J.R. 1981. Physical and chemical properties of Vertisols and their management. Pages 80-93 *in* Vertisols and Rice Soils of the Tropics: Transactions of the 12th International Congress of Soil Science, vol. 3; 8-16 Feb 1982, New Delhi, India.

WILLEY, R.W. 1981. Improved intercropping systems for small holders in the semi-arid tropics. Presentcd at the World Bank Symposium on Promoting Increased Food Production in the 1980's, 5-9 Jan 1981, Washington, D.C., USA.

WILLEY, R.W., NATARAJAN, M., REDDY, M.S., RAO, M.R., NAMBIAR, P.T.C., KANNAIYAN, J., and BHATNAGAR, V.S. 1982. Intercropping studies with annual crops. Presented at the Ciba Foundation Symposium No. 97 on Better Crops for Food, 14-16 Sept 1982, London, UK.

WILLEY, R.W., REDDY, M.S., NATARAJAN, M., and RAO, M.R. 1982. Improved intercropping systems for the SAT. Presented at the IRAT/ICRISAT Meeting on Soil Fertility and Nitrogen Management. 13-15 Apr 1982, ICRISAT, Patancheru, A.P., India.

WILLEY, R.W., RAO, M.R., REDDY, M.S., and NATARAJAN, M. 1981. Cropping systems with sorghum. Pages 477-490 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

Theses

BHALLA, S.S. 1982. Evaluation of some design parameters of a seed and fertilizer drill. M. Engg. thesis, Asian Institute of Technology, AIT, Bangkok.

KAUSALYA.T. 1982. Effect of cultivation on mineralization of organic matter in soil. Ph.D. thesis, G.B. Pant University of Agriculutre and Technology, Pantnagar, U.P., India.

KOTESWARA RAO, J. 1982. Investigations with nutritional disorders causing chlorosis of groundnut *(Arachis hypogaea,* L.) at ICRISAT Center. M.Sc. thesis, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad, India.

ECONOMICS

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ECONOMICS

Assessment of Deep Vertisol Technology Options

Research began at ICRISAT Center, Patancheru, in 1974 on operational-scale, deep Vertisol watersheds of 1 to 5 hectares to enable crops to be profitably grown in both the rainy and postrainy seasons. The traditional practice in assured rainfall (>750 mm) zones with deep Vertisols in India is to fallow the land in the rainy season and grow crops like sorghum, chickpea, and wheat only in the postrainy season on residual moisture. The extent of such rainy season fallowing, not precisely known, is estimated at 5 to 12 million hectares. Results of research at 1CRISAT Center reported last year (ICRISAT Annual Report 1981, pp.287-296) suggested that the following technology options would produce crops during the former fallow period:

- cultivating the land immediately after the previous postrainy season crop before the soil hardens;
- improving drainage by smoothing land and installing field and community drainage channels and using graded broadbeds and furrows, all designed with the aid of a detailed topographical survey;
- dry seeding crops before the monsoon rains arrive;
- using improved seeds and moderate amounts of fertilizers;
- improving placement of seeds and fertilizers for better crop stands; and
- improving plant protection, particularly of legume crops.

To verify whether the experience we had at ICRISAT Center and in cooperative research with Indian institutions could be replicated in farmers' fields, we and colleagues in the Farming Systems Research Program early in 1981 initiated an on-farm verification experiment in Taddanpally village, 42 km northwest of ICRISAT (Ryan et al. 1982). The village, in Medak District near Sangareddy, is representative of the rainy-season fallow, deep Vertisol region with assured rainfall. We chose for the experiment a small watershed of 15.42 hectares involving 14 farmers.

Because the Taddanpally experiment was as much a test of the ability of the delivery systems to support the demands the improved technology options require, as it was of the technical and economic performance of the options, we tried to keep subsidies to the minimum and encouraged farmers to use existing sources of credit and supplies. Officers of the Andhra Pradesh Department of Agriculture, the All India Coordinated Research Project for Dryland Agriculture, the Andhra Pradesh Agricultural University, and ICRISAT all were involved.

The elements provided free to the 14 farmers which they normally would pay for in full or in part were:

- use of wheeled tool carriers (2) and the improved implements that accompany them;
- construction of a main drainage channel serving the whole watershed;
- use of power sprayers;
- surveying the watershed;
- rodent control.

Fertilizers, seeds, pesticides, petrol, hired labor, and bullocks had to be provided or paid for by the cooperating farmers with either cash or credit. The Department of Agriculture, with the occasional assistance of ICRISAT, ensured the timely availability of those elements in Taddanpally village or in Sangareddy, some 13 km away. ICRISAT also provided intensive scientific and technical guidance.

Deep Vertisols are hard to plow when dry, and farmers often put teams of bullocks together to provide the necessary power for plowing each other's fields. The new technology requires that farmers cooperate, but offers them gains in return.

Extensive discussions were held with the farmers of Taddanpally to ensure cooperation; and they visited ICRISAT several times to become familiar with the technology options. We think those two factors were keys to convincing farmers both of our good intentions and of the technology's potential.

ICRISAT's guarantee that participating farmers would earn no less than they would expect from crops under traditional management helped obtain their cooperation. In that connection, as well as for "control" data, we monitored inputs/outputs on nearby plots selected as representative of traditional cropping patterns.

Soil conservation engineers from ICRISAT and the Andhra Pradesh Department of Agriculture surveyed the land and planned the watershed, leaving existing property boundaries in place. The farmers smoothed the land and made the drainageways designed in their own plots, using their animals and equipment. But they used one of the two provided tool carriers behind their bullocks for most other operations. Weak animals and hard soils presented some difficulties with seedbed preparation.

Development operations, excluding construction of the main drain and surveying, involved 24 bullock pair hours/ha and 31 man hours/ha.

The farmers were not willing to work collectively to install the necessary community drains to connect the watershed and the existing main drainage system, so the watershed did not drain properly during the very heavy, early rains, and lower parts of some fields flooded. After the farmers saw the flooding and recognized potential production losses to the emerging rainy-season crops, we persuaded them to help construct the community drains. The Andhra Pradesh Department of Agriculture paid for the labor to put the community drains in place.

Total costs of developing the watershed were modest (Rs. 254 per hectare), somewhat less than the Rs. 300 to Rs. 1100 per hectare needed to develop small watersheds in other village situations. Details of development expenditures in Taddanpally are given in Table 1.

ICR1SAT and the other research agencies recommended a range of suitable crops, but the farmers made their own choices. The 14 farmers chose nine crop combinations including those of one farmer who decided not to change his old ways. With one exception the crops did extremely well and far exceeded anything else in the vicinity. Not surprisingly, some new problems such as *Striga* weed developed. And as predicted, threshing—sometimes with unconventional mechanization—and storage were problems, particularly because the year was so wet (total rainfall 871 mm; September 241 mm) that sorghum heads did not dry in the field. Ineffective control of pod borer on pigeonpeas led to substantially reduced yields, 500 kg/ha instead of 1300 kg/ha estimated at the early podding stage.

Despite those problems the technology options performed extremely well (Fig. 1). Averaged over the nine cropping systems on the improved watershed, profits were Rs. 3059/ha, compared with Rs. 1625/ha from traditional systems (dominated by rainy-season fallow and postrainy-season sorghum). The improved systems involved an additional operating expenditure of Rs. 588/ha, but they generated increased average profits of Rs.1434/ ha. Those data show a 244% rate of return on the added expenditure, confirming the experience at ICRISAT Center (250%), and giving us confidence about the technology options on village farms.

Table 1. Development costs of Taddanpally watershed.

Activity	Cost (Rs/ha)
Surveying[1]	50
Land smoothing	9
Broadbed-and-furrow system	92
Private drain construction	8
Rodent control[1]	7
Main drain construction and planting of Soo-babul trees	88
Total	254

1. Borne by the Andhra Pradesh Department of Agriculture; other costs borne by farmers.

During the Taddanpally experiment several policy issues arose, and require attention before our technology options can be regarded as a real potential. ICRISAT scientists have been actively involved in dialogues with policy makers to ensure that the issues are addressed—a prerequisite for rapid transfer of technology. Major issues are as follows.

- Bullock power may be a problem for small farmers who may require loans for custom hiring or purchase.
- Special government programs may be necessary to construct community drainage when farmers do not agree to cooperate and construct with their own or borrowed resources.
- Markets may be needed for new crops in the improved system.
- Credit schemes and additional bank offices enabling purchase and custom-hiring of wheeled tool carriers should be available. Their density in the deep Vertisol regions of Andhra Pradesh is far less than in most other states.
- Farmers should not be required to repay rainy season loans before receiving loans for postrainy season crops as that delays essential operations; one annual loan should be negotiated with two or more disbursements.
- More fertilizer, plant protection, and chemical distribution centers are a major need.
- National research and extension staff must be trained in the basic components of the technology so they can modify and adapt it to local situations; perhaps the Training and

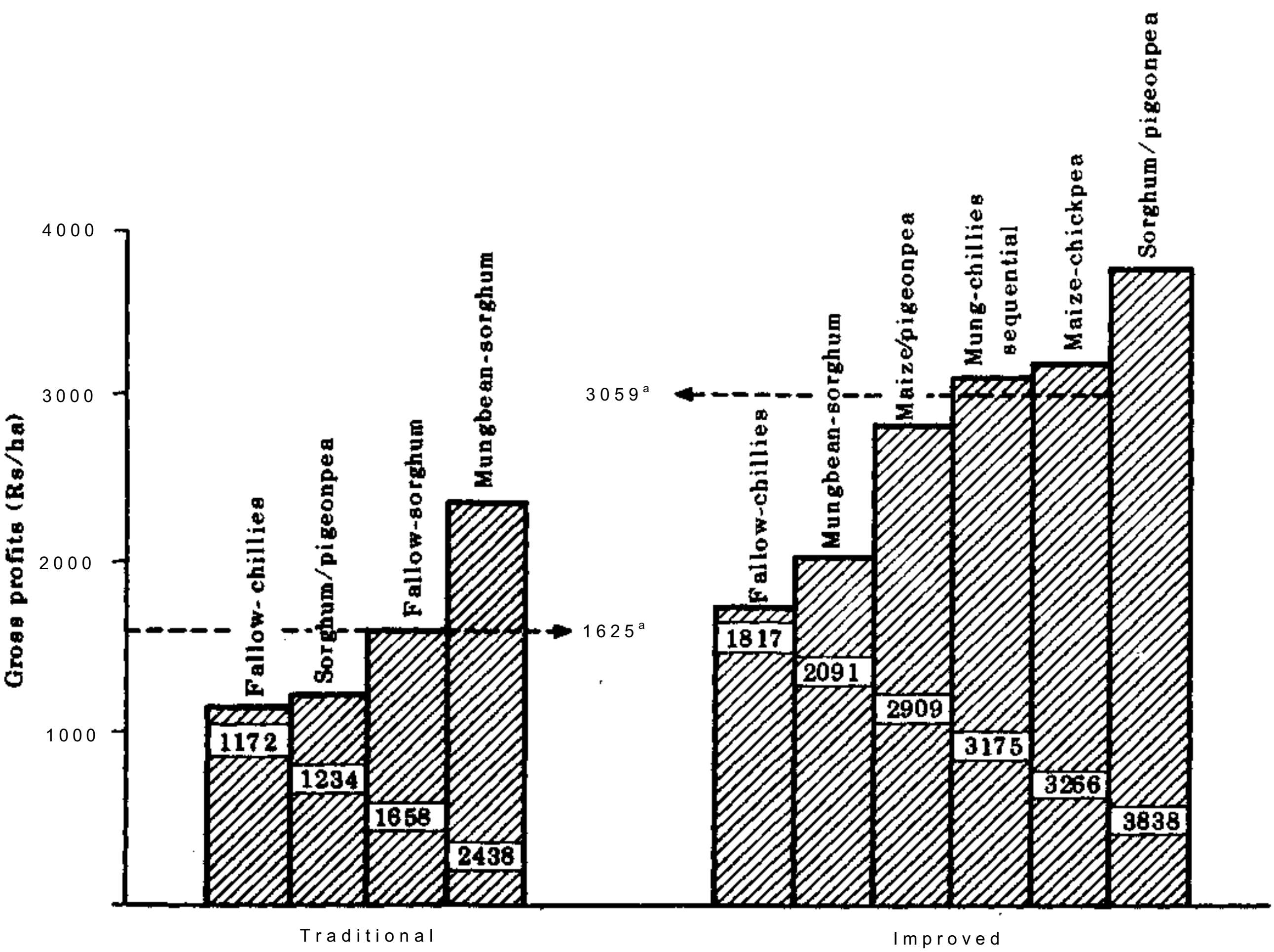
Visit (T and V) system could be effectively used.

The relative success of the Taddanpally experiment led to a further experimental area in adjoining Sultanpur village in 1982/83. It involves 17 farmers and a watershed of 35.2 hectares.

Because only 6 of the original 14 farmers in Taddanpally in 1981/82 decided to continue participating in the project in 1982/83, Sarin and Walker (1982, Economics Program progress report 44) studied perceptions of the 14 farmers regarding their 1981/82 experiences with the technology options.

Perceptions on the adequacy of field drainage in the past differed sharply between continuing participants and dropouts. Participants viewed poor field drainage (before the project was initiated) as a constraint to rainy-season cropping; the dropouts said drainage was not a problem. The participants' perception likely magnified for them the potential of the improved technology to increase productivity.

Even the participants believed that other constraints were equally or more important than field drainage. *Striga* in sorghum and pod borer in pigeonpeas were cited by all farmers as persistent yield reducers in rainy-season cropping. Uncertain control of those two pests made



a. Weighted averages over all cropping systems.

Figure 1. Gross profits from major cropping system in Taddanpally, 1981/82.

On-farm transfer: when ICRISAT's technology options were tried out on farmers' fields at Taddanpally village in Andhra Pradesh, India, returns to improved soil and water management were 244% of the added costs of preparing land and using new inputs, confirming the 250% obtaining at ICRISAT Center.

postrainy-season cropping appear more attractive to many watershed farmers.

Higher per-hectare profits in 1981/82 associated positively with participation by Taddanpally farmers in 1982/83. Per-hectare profits as an explanatory variable in a probit equation correctly predicted participation or nonparticipation in 1982/83 for 9 of the 11 decision-makers. (Only 11 of the 14 farmers involved make management decisions). Participants invested more of their family labor resources on a per hectare basis, so the increased demands that the improved watershed technology places on managerial and supervisory time may have been a disincentive to continue participating. If results in 1982/83 are as promising as last year's, we expect some of the dropouts to participate again in 1983/84.

Features of Traditional Village Farming Systems

Coverage in 1982

Much of our 1982 work was based on data collected and experience gained in the 1CRISAT Village-Level Studies (VLS), which are highlighted in ICR1SAT Annual Report 1979/80, pp. 233-234.

In 1982 we were active in seven villages in five broad agroclimatic, soil, and cropping environments in the SAT areas of India (Fig. 2). The villages vary widely in characteristics important in developing and transferring technology (Table 2).

Table 2. Basic features of the 1982 VLS villages.

	State, (district), and village						
	Andhra Pradesh (Mahbubnagar)	Maharashtra (Sholapur)	Maharashtra (Akola)	Gujarat (Sabarkantha)		Madhya Pradesh (Raisen)	
Characteristic features	Aurepalle	Shirapur	Kanzara	Rampura	Boriya	Rampura Kalan	Papda
Soil type	Alfisols	Medium to deep Vertisols	Medium Vertisols	Sandy and sandy loam		Medium to deep Vertisols	
Annual rainfall (mm)[1]	653	597	976	702	978	1350	
Average size of operational holding (ha)	4.0	4.8	4.6	2.2	1.4	5.1	5.4
Extent of intercropping[2]	36	47	74	23	70	46	10
Area operated per pair of bullocks (ha)	4.8	11.8	8.0	3.8	4.2	5.3	6.3
Area under ICRISAT crops[2]	35	84	32	37	47	19	9
Irrigation[2]	20	11	4	38	13	2	2
Intensity of cropping (%)[3]	115	110	107	146	120	108	101
Postrainy season cropping[2]	17	67	6	33	18	76	90

1. For the Madhya Pradesh villages, rainfall data are taken from official records in a neighboring town. For the other villages, daily data are recorded from rain gauges in the villages.
2. % of gross cropped area.
3. More than 100% means that farmers take more than one crop a year on some portion of their area.

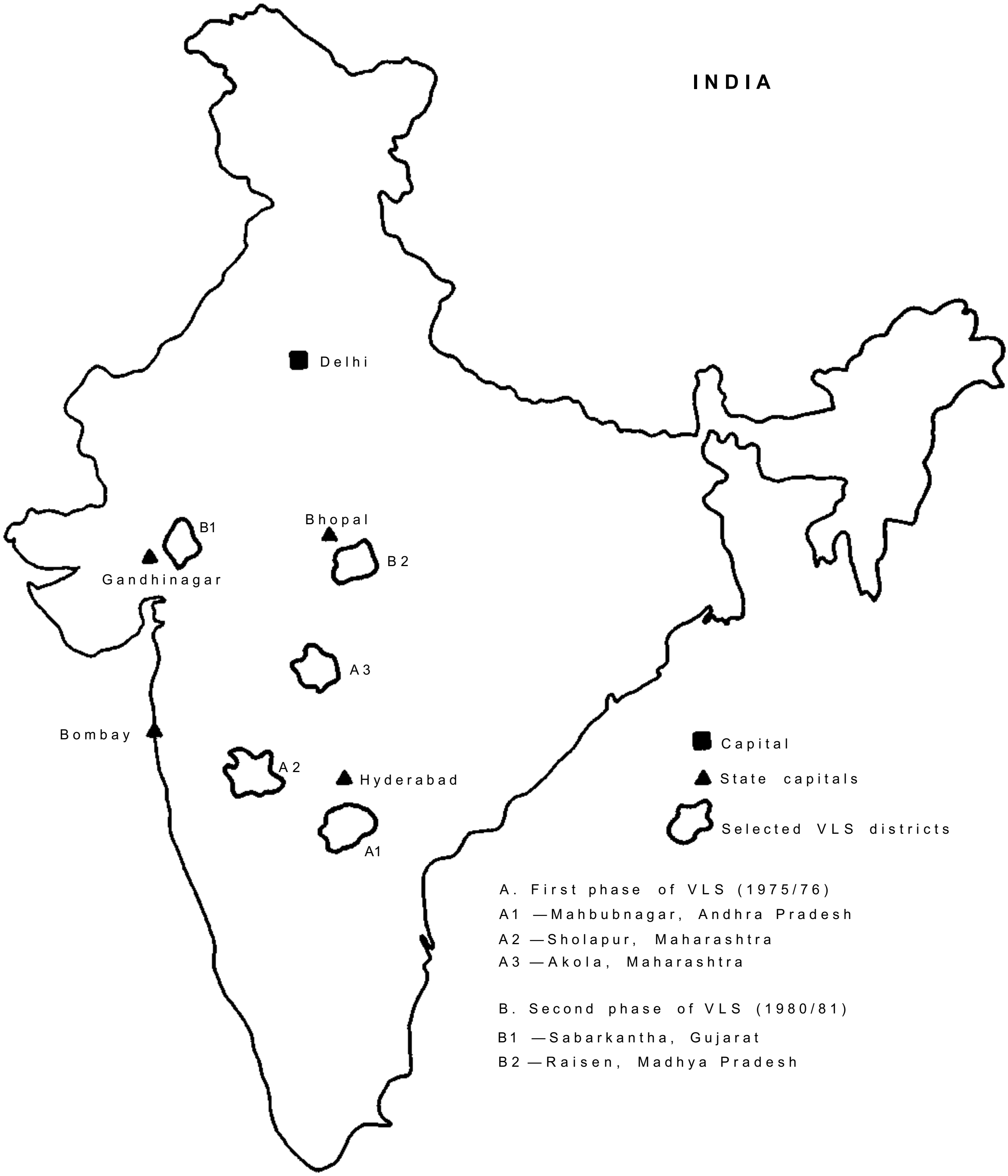


Figure 2. Areas identified for village selection in ICRISAT's Village-Level Studies.

Since July 1975 we have posted resident investigators in the three "older" villages of Aurepalle (Mahbubnagar District), Shirapur (Sholapur), and Kanzara (Akola). In early 1980 we initiated Village-Level Studies in Gujarat to focus on an important groundnut- and pearl millet-producing region. In 1981 we started Village-Level Studies in Madhya Pradesh to cover a rainfall-assured environment where we think the deep Vertisol technology options are promising. The studies in Gujarat and Madhya Pradesh are carried out in collaboration with state agricultural universities.

Traditional Farming Systems in Gujarat

Jointly with collaborators from Gujarat Agricultural University, we described (Singh and Singh 1982, Economics Program progress report 35) some of the salient agronomic and socioeconomic features of the two Gujarat villages, Rampura and Boriya. They differ markedly in social organization, access to irrigation, institutions, and economic dynamism. Boriya, with less access to well irrigation, has a wider array of cropping systems than the "older" study villages in Andhra Pradesh and Maharashtra. Livestock contribute heavily to household income in both villages in Gujarat. Our initial findings suggest that the two Gujarat villages offer fruitful sites to study groundnut and pearl millet production, improved components in intercropping systems, crop x livestock interactions, and the role of social dynamics in rural transformation.

The Economics of Slowly Improving Crops

Using plot and crop data from six VLS villages, we evaluated constraints to increasing the production of slowly improving crops (Jodha and Singh 1982) defined as crops whose production in recent years has not kept pace with expectations—sorghum, pearl millet, pigeonpea, chickpea, and other pulses. In general they are produced by poor farmers, are of low value, and are usually consumed by poor consumers. Compared with superior cereals and cash crops, the slowly improving crops are more capable of surviving on a poor resource base.

Data in Table 3 show the poverty of their resource base. Superior cereals like rice and wheat garner most of the resources. Percentage

Table 3. Percentages of total area devoted to crops receiving irrigation, fertilizer, and manure in six VLS villages in three regions.

	Irrigation			Fertilizer			Manure		
Crop	A	S	M1	A	S	M	A	S	M
Sorghum	0	8	4	0	3	17	0	7	0
Pulses	1	5	0	0	0	4	7	4	8
Coarse cereal-based mixtures	1	6	0	6	3	0	2	14	6
Pulse-based mixtures	8	2	.3	7	I	-	0	0	-
Paddy[2]	0	17	100	23	35	96	12	1	32
Wheat[2]	91	82	100	91	36	0	0	7	0
Groundnut and mixtures	6	29	94	21	20	74	30	10	4
Cotton and mixtures	2	-	-	19	-	-	6	-	-
Sugarcane	-	100	-	-	56	-	-	34	-
Vegetables	49	93	30	32	47	24	35	19	8

1. A, S, and M designate the Akola, Sholapur, and Mahbubnagar regions, respectively.
2. Paddy in Akola and Sholapur and wheat in Mahbubnagar are planted on too few fields to offer meaningful comparisons.
3. Dash (-) represents crop not grown.

shares of irrigation, fertilizer, and manure allocated to coarse cereals, pulses, and their mixtures are disproportionately low.

We see no easy or immediate solutions to the above constraints. One answer is investments in the development and transfer of low-cost technology; diversifying demand is another. Increasing the total availability of purchased inputs would relieve the resource "starvation" of coarse grains and pulses.

Size and Composition of Rural Income

The level and distribution of income strongly influence both what technologies farmers adopt and how fast they spread, which, in turn, condition the size and distribution of incomes. We studied rural income in six SAT villages of India (Singh, Asokan, and Walker 1982, Economics Program progress report 33).

The farming and socioeconomic activities of a panel of 40 households have been monitored in each village starting in 1975. The panel is from a random stratified sample of small-, medium-, and large-sized farming and landless-labor households. Multiple interviews (at least once a month) by a resident village investigator enhance the reliability of the household-income data.

Rural incomes are estimated for three cropping years, 1975/76 to 1977/78, for Kanzara, Shirapur, Aurepalle, and Dokur; and for two cropping years, 1975/76 and 1976/77, for Kinkheda and Kalman. The income concept used is net household income, which represents returns to family labor, owned bullocks, owned capital, owned land, and management. Income and expenses from both farm and nonfarm activities are considered in estimating net household income.

Rural income is extremely low in the six villages. The median per capita, annual income averaged across the six villages was only Rs. 373 (U.S. $42 in 1977 prices). The all-village mean per capita income of Rs. 483 was less than half the all-India per capita income—Rs. 1080 for 1977. Only about 8% of the 240 sampled households had per capita incomes above U.S. $150 and only one household had a net income superior to U.S. $2500, during any one of the three cropping years.

When we divide the 240 households in the six villages into their respective farm-size groups (Table 4), the all-village median per capita income estimates are surprisingly close for the first three farm-size classes. But large-farm households received about 160% more than landless-labor, small-farm, and medium-farm households. Because larger farms were associated with larger families, income differences between farm-size classes were much sharper for household than for per capita comparisons.

Most of the households derived their income from cropping activities and/or hiring out their labor, mainly in each village's casual agricultural labor market (Table 5). Contributions made by crop production and labor to net household income were roughly the same across the six villages. Labor income was not restricted to landless households. The average income shares supplied by labor earnings to gross household income were 40, 26, and 13% for small-, medium-, and large-farm size classes. Other sources of income were somewhat important in some villages but not in others.

Table 4. Median net per capita annual income (in rupees)[1] by household size group in six SAT villages of India.

		Household class		
Village	Landless labor	Small	Medium	Large
Aurepalle	231	226	340	753
Dokur	421	306	461	575
Shirapur	320	439	392	449
Kalman	195	319	307	281
Kanzara	485	469	406	747
Kinkheda	380	416	410	543
All-village, average	320	328	367	540

1. The simple average of the median estimates for the three cropping years.

Table 5. Composition (in %) of net household income by source in six SAT villages of India.

	Income sources					
ViUage	Crops	Labor[1]	Trade and handicraft	Rental	Livestock[2]	Others
Aurepalle	29.8	32.8	11.6	-0.8	25.5	1.1
Dokur	46.1	46.3	1.1	2.2	2.0	2.3
Shirapur	33.7	42.6	0.2	2.2	15.0	6.3
Kalman	46.0	42.1	4.1	4.4	0.8	2.6
Kanzara	43.9	38.7	2.6	1.5	9.0	4.3
Kinkheda	43.4	40.8	5.3	0.6	13.1	-3.2
All-village average[3]	40.6	40.6	3.9	1.6	10.9	2.4

1. Labor income includes the value of labor used for crop production and livestock maintenance as an indirect contribution to income from family labor.
2. Livestock income includes the value of owned bullock labor used on own farm as an indirect contribution to livestock income.
3. Unweighted values because the estimates are not adjusted for sampling fractions between landless laborers and cultivator households in each village.

Women contribute heavily to household labor income (Table 6). Their share in labor income varies considerably by village and region. In the irrigated paddy village of Dokur, a strong demand for female labor leads to higher probabilities of employment and higher wages there than in the other five villages. In Aurepalle, labor market participation for males is extremely low. Women play a relatively less important role as contributors to household labor income in the four more-northern villages in Maharashtra.

The across-village income comparisons partially confirm what other studies have suggested are powerful determinants of income in SAT India: how the agricultural labor market functions, the quality of resource base, and access to more productive cropping technologies.

Low incomes, especially for small- and medium-sized farm households, magnify the lack of access to credit, a constraint to adopting improved technologies, particularly indivisible technologies. Our results emphasize the need to understand the workings of rural financial markets in SAT India. They also reflect the consequences of underinvestment in dryland agriculture.

Determinants of Rural Villagers' Wages

There are few empirical estimates in developing countries of labor-supply responses by rural villagers to changes in daily wages. Knowledge of the determinants of wages and effects of wage variations on market and farm work-participation decisions is essential to assess likely consequences on employment and wages of technological change that increases the demand for labor.

During 1982 we used 1975-78 data (from ICRISAT's Village-Level Studies) to determine whether individual human capital attributes and such demand factors as nutritional status, health, socioeconomic status, season, and type of agroclimatic region affect wages rural laborers receive (Ryan 1982, Economics Program progress report 38). During the 1975-78 study period, men's wages averaged Rs. 3.16 per day (U.S. $0.40), 70% higher than the Rs. 1.78 (U.S. $0.23) paid women. Wage functions were fitted separately for men and women and the derived elasticities of wages with respect to changes in the explanatory variables are shown in Table 7.

Table 6. Family contributions to labor income (rupees) in six SAT villages of India.

Village[a]	Family member category: Men	Women	Children	Total
Aurepalle	58 (24)[b]	154 (63)	32 (13)	244
Dokur	235 (29)	569 (69)	15 (2)	819
Shirapur	507 (69)	184 (25)	48 (6)	739
Kalman	351 (67)	134 (26)	35 (7)	520
Kanzara	574 (60)	328 (35)	46 (5)	948
Kinkheda	355 (56)	257 (40)	25 (4)	637
All-village average	346 (53)	279 (42)	34 (5)	659

a. Unweighted values because the estimates are not adjusted for sampling fractions between landless labor and cultivator households in each village.

b. Figures in parentheses are percentages of total labor income.

Human capital variables such as age, education, experience, skill, and physical and nutritional well-being were important in explaining variations in wages paid men in the daily labor market in the six villages of south India. Contrary to assumptions from many recent studies on tenancy contracts in developing countries, our results suggest that men may be paid a wage premium for labor and management skills. Individual human capital attributes were less important than such demand factors as type of season, village characteristics, and presence of nearby public works projects in explaining women's wages. That women are generally less geographically mobile than men helps explain the significance of local demand in forming their wage rates.

If men remain occupationally immobile, investments in improving nutrition appear to give a higher immediate payoff than investments in improving their education. Only if this increased education leads to a change in the type of labor market where men seek employment would more education likely return more than improved nutrition. But new agricultural technology in the villages putting a premium on education could increase rates of return to education. Now the return does not exceed 2.5% for men, and is less than 0.6% for women who remain in the villages' daily labor markets.

The returns (higher wages) to improved nutrition of men being as high as our weight/ height elasticity indicates, and virtually nonexistent for women, would provide an economic rationalization for men generally receiving priority when food supplies are distributed at meals. Frequent failure of special nutrition programs, aimed at such nutritionally vulnerable groups as preschool children and pregnant and lactating women, may stem from the added food supplies

Table 7. Elasticities of wages for males and females.[1]

Indicated factor	Wage elasticity: Males	Females
Age	0.06**	0.02
Education	0.05**	0.004
Weight/ height index	0.51**	-0.01
Skill dummy	11.10**	5.90
Experience dummy	0.70	-0.40
Disability dummy	-42.90**	-6.70**
Foodgrain price index	0.08	0.09**
Proportion of kind wages	0.02**	0.02**
Excess rainfall	-0.05	-0.12**
Government project intensity	0.02	0.11**
If not household head (dummy)	-5.90*	-1.60
Peak-season dummy	0.50	3.0*

1. For dummy variables the number in the table refers to the percentage change in wages generated by the dummy. For all other variables the elasticity is given at the arithmetic mean of the variable. In addition to variables shown in the table, we included dummy variables representing each (village by year) interaction. Twelve of the 18 were significant in both equations (not shown).

going to male household members to generate increased income. If so, special targeted nutrition programs may not succeed until they include adult males. The parameters derived in this study may be used to measure productivity effects of improving the physical and nutritional well-being of adult males in an integrated program. Including males might significantly enhance benefit-cost ratios of the programs, while ensuring that vulnerable groups receive the nutritional benefits intended.

Risk in India's Semi-Arid Tropics

This past year we finished several studies that let us analyze diverse dimensions of risk in SAT India. In the 1977/78 ICRISAT Annual Report (pp. 235-237), we presented initial findings on an experimental approach to measure the extent and distribution of risk aversion among SAT households. The experimental approach has given good results and two follow-up studies reported here have extended the earlier estimates in two significant directions. The studies are now completed, which ends our research on risk attitudes in India's SAT.

The other four studies reported here share a common objective of empirically documenting sources of risk in SAT agriculture. Such research lays the foundation for evaluating impacts of institutional and technological policies on production and consumption instability.

Risk Attitudes and Production Decisions

This research was to determine whether risk attitudes—measured with experimental games—could account for variation in the actions of VLS respondents when they faced several "risky" decisions (Binswanger et al. 1982, Economics Program progress report 42). The decisions ranged from investing in fertilizer and irrigation to choosing strategies relating to fallow land and sowing time. Differences in risk aversion markedly influenced some agricultural decisions. Farmer-to-farmer differences in risk aversion were significant determinants in investing in irrigation, accumulating wealth, and fallowing lands. Farmers less averse to risk also applied more fertilizer per hectare and took more chances on sowing with unseasonal early rains but not significantly ($P < 0.05$) more than their more risk-averse neighbors.

The results show that measured attitudes toward risk revealed by real gambling decisions have operational significance on agricultural decisions. Still, farmer-to-farmer variation in risk aversion does not explain a large proportion of variation in agricultural decisions in and across SAT villages. The effects of differential risk aversion on using fertilizer and fallowing are overwhelmed by differences in agroclimatic and other regional endowments, and by differences in wealth, experience with fertilizers, and irrigation intensity. When differences in both risk aversion and education significantly influenced agricultural decisions, their impacts were about equal.

The foregoing does not imply that variations in risk among production techniques or across agroclimatic regions are unimportant. Our earlier research showed the vast majority of farmers moderately averse to risk and, therefore, likely to respond rather similarly and significantly to differences in risk.

Theoretical Implications of Experimental Evidence on Farmer Attitudes Toward Risk

We completed our research on risk attitudes by considering what the results from experimental measurement implied for theories of behavior under uncertainty (Binswanger 1981). We tested hypotheses on the impact of changes in household wealth and income and in the size of real gambling games on levels of risk aversion. We found that responses of participants in the experimental games were inconsistent with predictions from security-based decision theories featuring minimum probability levels of achieving threshold or target levels of income. The experimental choices made by participants agreed with the hypothesis that decision makers evaluate alternatives from a perspective of gains and losses rather than from final states of wealth. This contradicts the conventional expected utility theory.

Our experimental work on risk attitudes in India's SAT has been replicated in studies in Southeast Asia and Central America, which confirm our earlier results in India's SAT.

Regional Effects of Stabilization Policies

Government attempts to stabilize farmers' income through price support or crop insurance programs often are advocated on the basis of potential efficiency and equity impacts on poor farmers. To be effective, stabilization policies must reduce income variability, particularly among poor farmers who tend to be concentrated in disadvantaged agroclimatic zones such as India's SAT.

In this study, we analyzed the extent that potential benefits from stabilization policies differ according to agroclimatic and development characteristics of the different regions (Barah and Binswanger 1982, Economics Program progress report 37). We measured the variability of total crop revenue per hectare of gross cropped area across 93 districts in four SAT states of India with cropping-year data from 1956/57 to 1974/75. By simple covariance techniques, we partitioned the variability into price, yield, and yield x price interaction components. Then we made interregional comparisons of the potential impacts of price or yield stabilization policies on total revenue variability.

We divided the 93 districts into three annual rainfall and irrigation groups, then classified the 5 districts where rainfall exceeded 1500 mm/year as humid tropical, and grouped the remaining 88 districts into 62 nonirrigated (NSAT) districts and 26 irrigated (ISAT) districts—less or more than 25% of gross cropped area irrigated.

Information on the strength of yield, price, and yield x price interaction effects in determining gross revenue variability is summarized in Figure 3. The overall yield and price components are plotted on the vertical and horizontal axes, respectively. The yield x price interaction is measured as the horizontal or vertical distance between the point and the line (100,100). Most of the NSAT and ISAT districts had negative yield x price interaction terms, which indicates that the full impact of fluctuations in yields and prices is not transmitted to farm income.

The relative importance of yield versus price risk is measured by each district's relative position to line OA. For points above the line, the yield component exceeds the price component; the reverse is true for points below OA. For 50 of the 62 NSAT districts the yield component was markedly larger than the price component. But for 21 of the 26 ISAT districts, the price component exceeded the yield component, and it was much higher in many ISAT districts. The price component exceeded the yield component in all five of the humid tropical districts.

Clearly, the predominant risk is yield variability for the 62 NSAT districts, but it is price variability for the 26 ISAT and the 5 humid tropical districts.

Complete stabilization of all prices would reduce the price and the yield x price interaction components to zero. The remaining variability then would equal the yield component. For the 20 districts above the horizontal line at the 100 level (where the yield component exceeds 100% of the explained variation), complete price,.stabilization would increase the revenue risk; 18 of the 20 are from the poorer NSAT and would be hurt by complete price stabilization. But complete price stabilization would reduce revenue risk for most districts, and would exceed 1/3 of the explained variation for 51 of the 93 districts.

The major beneficiaries of reduced price variability would be farmers in the agriculturally most advanced districts. For example, West Godavari in Andhra Pradesh, the district with the largest impact from price stabilization (No. 47 in Fig.3), also had the highest revenue per hectare (Rs. 3483).

Normally, governments attempt to stabilize prices only for a few agricultural commodities. Similarly, crop insurance schemes normally are restricted to individual crops. Perfect rice-price stabilization would reduce revenue variability in the irrigated SAT by 25% (Table 8), but its impact would be uneven. Some districts would experience large reductions in variability, while revenue variability would increase in others. Benefits to the poorer NSAT would be exceedingly minor. In contrast, the NSAT districts as a group would benefit more than the ISAT districts from a crop insurance scheme for rice aimed at yield stabilization (Table 8). That is because many NSAT districts still have fairly large rice areas. And the rice yields vary widely because rice is either rainfed (in high-rainfall districts) or irrigated from such relatively unreliable water sources as small reservoirs or wells that depend primarily on local rainfall.

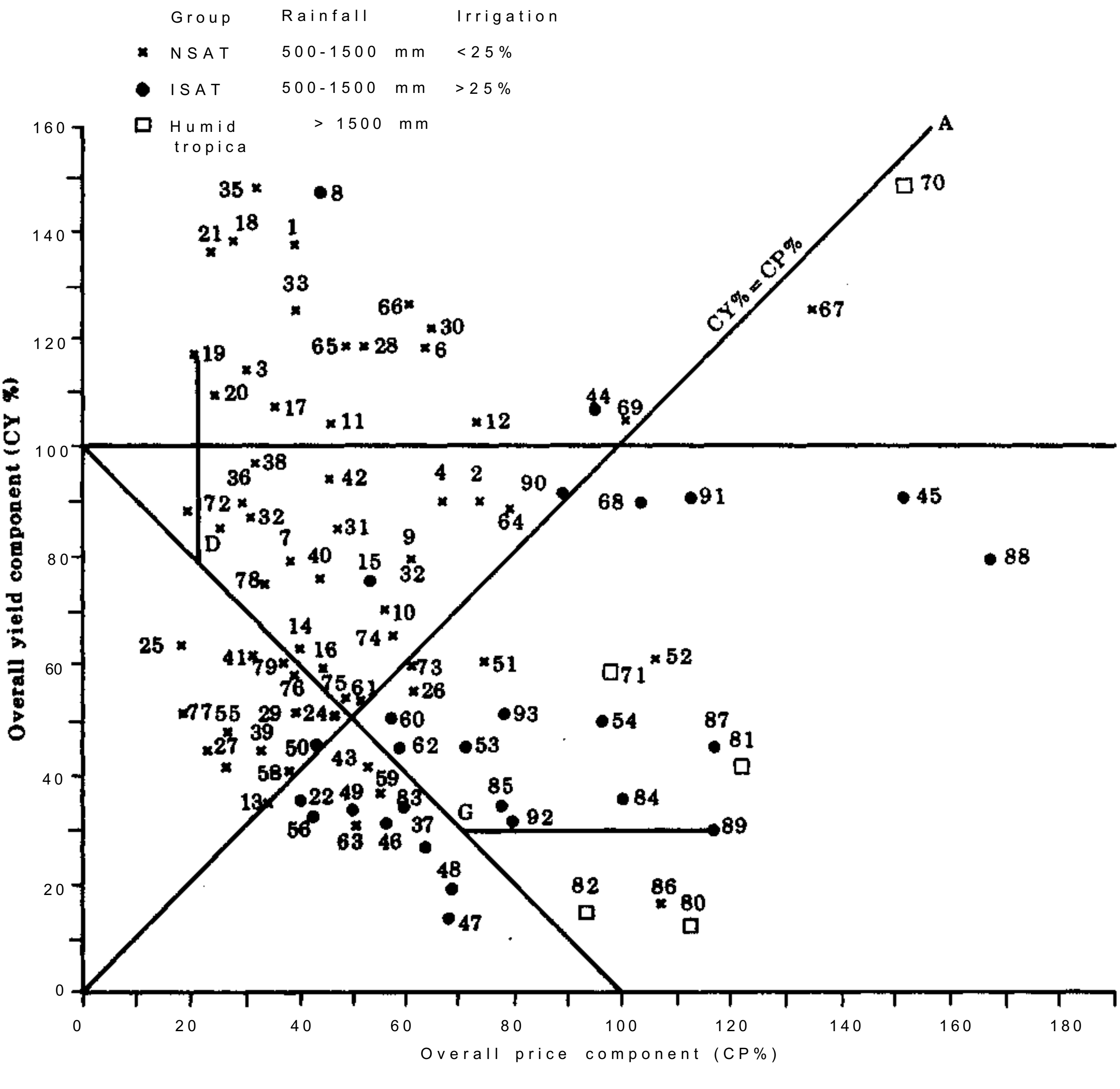


Figure 3. Overall yield component versus overall price component from 93 Indian districts classified by rainfall.

Table 8. Average effects of stabilization policies across India's SAT districts.

Stabilization policy	Non-irrigated	Irrigated	All districts
	(Change in gross revenue variability in %)		
Rice price	-2.71	-25.35	-11.30
Rice yield	-13.12	-10.62	-10.72
Sorghum price	-9.38	-5.07	-7.47
Sorghum yield	-15.21	-2.87	-11.11

Sorghum price stabilization and sorghum crop insurance both would provide larger benefits to the NSAT than to the ISAT (Table 8). Perfect crop insurance for sorghum would reduce revenue variability in the NSAT an average 15%.

In summary, our analysis suggests that price stabilization programs likely would not benefit farmers in poorer SAT regions and would be detrimental to some of them. Yield stabilization policies like insurance would more effectively produce crop income stability in dryland SAT districts. The potential benefits from crop insurance would be greatest if programs could be targeted to dominant crops in regions with highest yield risks. Still our analysis does not fully endorse crop insurance. Potential benefits of such yield stabilization policies must be weighed against their costs, including administrative costs.

Risk and Common Cropping Systems

Objectives of this research were: (a) to explain sources of yield variation in cropping systems commonly practiced in the ICRISAT VLS; (b) to test hypotheses on the shape of yield- and net-return distributions; and (c) to derive implications for assessing risks in generating technology (Walker and Subba Rao 1982, Economics Program progress report 41).

The common village cropping systems span a wide range of technology (Table 9). Some, like postrainy-season sorghum systems, use few, if any, improved inputs; others, like the irrigated paddy systems in Dokur, use inputs intensively for higher yields.

Traditional inputs appear not to substitute for purchased inputs. For example, proportionally more plots in rainy-season irrigated paddy production in Dokur receive farmyard manure than

Table 9. Technical description of common village cropping systems.

Village	Cropping system	Input use, % of total plots				
		Inorganic fertilizer	Farmyard manure	Pesticide	Improved cultivars	No. of plots
Aurepalle[1]	Cereal-pulse intercrop	0.6	13.0	1.2	0	169
	Sole castor	3.4	24.8	10.2	.3	177
Dokur[2]	Rainy season HYV paddy	87.8	43.5	4.2	100	237
	Postrainy season HYV paddy	94.7	1.3	1.3	100	76
Shirapur[2]	Postrainy season sorghum	0.8	2.2	0	0	406
Kalman[2]	Postrainy season sorghum	1.9	2.9	0	0	486
Kanzara[1]	Cotton intercrop 1	14.0	5.0	0	0	190
	Cotton intercrop 2	37.0	8.0	8.0	0	98
	HYV sorghum	60.0	1.0	46.0	100	78

1. Based on data for cropping years 1975/76 to 1980/81.
2. Based on data for cropping years 1975/76 to 1979/80.
3. Data were not collected on castor cultivar use before 1981. Many farmers have adopted improved castor varieties, and some use high-yielding hybrids from Gujarat when seed is available.

Table 10. Descriptive statistics for grain yield[1] and net returns[2] in common village cropping systems.

Village	Cropping system	Crop components in intercropping systems	Yield: Mean (kg/ha)	Yield: Range	Yield: Skewness	Net return: Mean (Rs/ha)	Net return: Range	Net return: Skewness
Aurepalle	Cereal/pulse intercrop	Sorghum	201	0- 539	0.03			
		Pearl millet	124	0- 412	0.65**	387	-211-1207	0.06
		Pigeonpea	27	0- 239	5.30**			
	Castor		256	0- 889	1.07**	404	-292-1660	1.26**
Dokur	Rainy season paddy		2906	0-5693	0.24	1582	-759-4734	0.27
	Postrainy season paddy		3332	949-5219	0.29	1564	-492-3756	0.03
Shirapur	Postrainy season sorghum		225	0-1384	3.44**	332	-215-2152	2.83**
Kalman	Postrainy season sorghum		199	0-1183	3.68**	323	-409-1404	1.22**
Kanzara	Cotton intercrop[1]	Cotton	135	5- 368	0.31*			
		Pigeonpea	40	0- 213	4.57**	503	- 79-1695	0.59**
		Sorghum	36	0- 260	5.09**			
	Cotton intercrop[2]	Cotton	178	30- 529	1.24**	592	- 84-2059	2.07**
		Pigeonpea	59	0- 192	0.92**			
	Hybrid sorghum		871	0-2649	0.16	641	-683-2116	0.02

1. Both yield and net return data have been adjusted for significant farmer effects.
2. Net returns to family labor, owned draft power, land, capital, and management.

plots of traditional crops in the other villages. Postrainy-season sorghum production is resource impoverished in both traditional and improved inputs.

The cropping systems can be grouped into three types based on use of improved inputs, particularly inorganic fertilizer: (a) traditional, (b) semiimproved, and (c) improved. Traditional cropping systems embrace the rainy-season cereal/ pulse intercrop and sole-cropped castor in Aurepalle and the postrainy-season sorghum systems in Shirapur and Kalman. Semiimproved applies to both cotton intercrop systems in Kanzara, although the cotton/pigeonpea intercrop uses more inorganic fertilizer than the more traditional cotton/ sorghum/ pigeonpea intercrop. The improved systems encompass the irrigated paddy systems in Dokur and the rainy-season hybrid sorghum in Kanzara.

Sources of yield variation were quantified by regression analysis. Agroclimatic variability significantly explained yield variation in the nine cropping systems and in most of their components. Farmer-to-farmer differences were proportionally more important in determining yield in the improved cropping systems. The absence of significant farmer-to-farmer differences on yield determination in the traditional cropping systems implies that reshuffling practices and inputs will not increase productivity. To increase productivity, new technological components must be generated. Soil variation in each village accounted for a good share of yield variation of postrainy-season sorghum in Shirapur and Kalman.

In general, both yield and net-return distributions in traditional and semiimproved cropping systems were positively skewed, while the improved cropping systems had normally distributed yields and net returns (Table 10). Intercropping that generates multiple crop products, and a high-fertility, rainfall-assured production environment lead to normal yield- and net-return distributions.

The assumption of distributions being normal made by mean variance analysis and other methods commonly used to evaluate risky choices may not be unduly restrictive for improved cropping systems and traditional intercrops. The cotton intercropping systems appear to be an exception, but both traditional and improved systems are dominated by cotton as it contributes 70 and 80% to the total value of their production.

Soil environment's role in conditioning the shape of yield- and net-return distributions is clearly illustrated in Table 11 with production data for postrainy-season sorghum in Shirapur and Kalman villages. Skewness in yields and net returns increases as soils become shallower and less productive. Returns are still positively skewed on deep Vertisols but when soil variability is omitted, skewness is not nearly so severe as conveyed in Table 10.

When practitioners assess risk in traditional and improved sole-cropped systems, it is likely that the shape of the two distributions will differ. Conventional risk management analysis, based

Table 11. Descriptive statistics on yield and net return distributions of postrainy-season sorghum cultivated on indicated soil types in Shirapur and Kalman.

Soil	Descriptive statistics: Median	Descriptive statistics: Skewness	Number of observations
	Grain yield (kg/ha)		
Deep black	319	2.15**	95
Medium black	190	*2.11***	261
Shallow black	127	5.73**	438
Gravely and others	64	7.38**	98
	Fodder yield (kg/ ha)		
Deep black	879	0.36	95
Medium black	694	1.26**	261
Shallow black	696	1.00**	438
Gravely and others	468	0.72**	98
	Net returns to own resources (Rs/ ha)		
Deep black	475	1.28**	95
Medium black	288	2.49**	261
Shallow black	237	3.61**	438
Gravely and others	117	4.32**	98

on the assumption of normality, will probably underestimate risk in switching from traditional to improved cropping systems when improved-system yields are normally distributed while traditional yields are positively skewed. Our results indicate that skewness influences the choice of cropping system when the estimated skewness coefficient exceeds 2.00 for one cropping system while the other is normally distributed.

Yield Instability and Supply Response

Much of ICRISAT's crop improvement research focuses on incorporating disease, insect, and environmental stress resistances into breeding material to enhance yield stability. Will improved yield stability in and of itself induce farmers to plant more area to a crop? We extended our research on risk and common cropping systems to look at that question for rainy-season cropping strategies in Kanzara village (Walker and Subba Rao 1982, Economics Program progress report 43).

When farmers substitute hybrid sorghum for competing local cotton/pigeonpea/sorghum systems, net crop income increases from Rs. 500 to 640 per hectare (Table 10) but the CV of income also rises from 58 to 91%. At existing levels of farmer risk aversion, measured by real gambling games, risk is a potential deterrent to planting more hybrid sorghum in the black-soil, cotton-growing region of Maharashtra. The underinvestment in hybrid sorghum production stemming from farmer risk aversion costs society equivalent to about 80 kg/ha (or 10% of average yield).

Relying on a portfolio analysis, we parametrically reduced the CV of hybrid sorghum yield to determine how sensitive area-supply response was to increased yield stability. The results (Fig.4) indicate that breeding for stability should return handsome dividends. A 30% reduction in the CV of sorghum yield, holding mean yield constant, would lead to an initial 46% increase in area planted to sorghum—the proportional increase from 0.28 to 0.41. The result is particularly encouraging because sorghum hybrids already have a fairly high yield potential.

Crop Failure

Little is known empirically about the importance or determinants of crop failure in the semi-arid tropics. It is an extreme and transparent consequence of interacting agroclimatic, biological, and soil factors.

We analyzed the field-level determinants of crop failure for 3805 plots cultivated by 180 farmers in six ICRISAT study villages from 1975/76 to 1977/78 (Singh and Walker 1982, Economics Program progress report 40). Sown fields not harvested (about 10% of the plots) were declared failures. The majority of such fields were in the drought-prone Sholapur region, where postrainy-season sorghum is commonly cultivated on Vertisols. The higher incidence of crop failure there limits the results to that region.

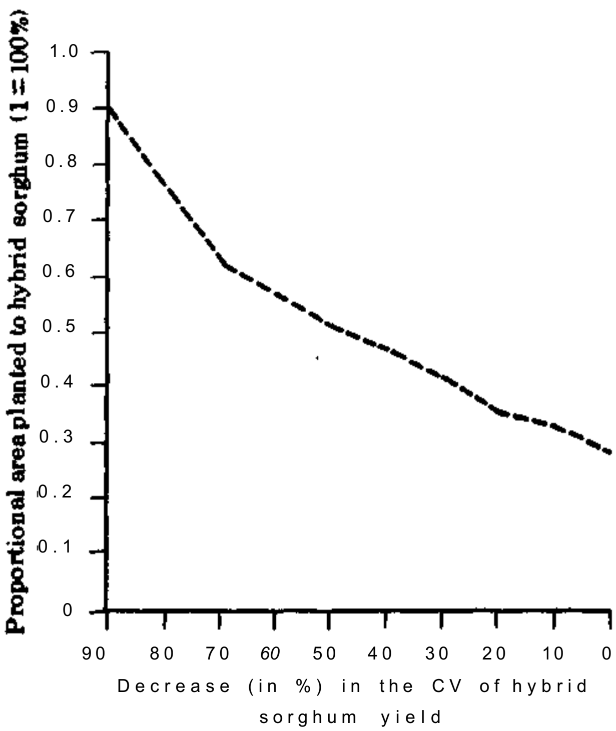


Figure 4. Supply response and yield stability of hybrid sorghum.

We used a probit model to quantify crop failure determinants. The strength of determinant effects can be evaluated with the predicted probabilities of crop failure reported in Table 12. Deeper soil, irrigation, cropping in the postrainy season, and village location in a more assured production environment significantly diminished crop failures. Subtle agroclimatic differences in the semi-arid tropics cause sharp differences in the incidence of crop failure. Across the six villages, estimated probabilities of crop failure ranged from 0.03 in Kinkheda to 0.26 in Shirapur, yet over the three cropping years only about 100 mm more rain fell annually in Kinkheda than in Shirapur. Our farm-level results support base data studies that point to the high risks associated with rainy-season cropping in Vertisols in a low-rainfall environment.

We used the estimated results to measure the quality and stability of the resource base across farm-size classes and land-tenancy groups. The results indicated that land quality of small farmers was inferior to that of large farmers in one village, superior in two villages, and did not differ significantly in the three other villages. Evidence strongly indicated that land quality of sharecropped plots was inferior to owner-operated plots in the Sholapur region.

Agricultural Marketing

Research at ICRISAT on agricultural marketing aims not only to describe the marketing channels of ICRISAT crops and of their inputs but also to evaluate the potential for improving agricultural marketing as an engine for agricultural development. Economic theory tells us that better agricultural marketing should increase aggregate productivity. To be able to guide policy makers regarding investments for improving market access, we measured the magnitude and time lag of the factors involved. The results show that agricultural marketing is important in generating and allocating capital within agriculture and in other sectors of the economy.

Work completed in 1982 reflects a wide spectrum of research in agricultural marketing. There are descriptive studies on the marketing of sorghum (von Oppen and Rao 1982) and of chickpea; a study quantifying the efficiency of market channels for ICRISAT crops in India (Raju and von Oppen 1982, Economics Program progress report 32); an overview of various analyses measuring the effect market access has on aggregate productivity (von Oppen, Rao, and Subba Rao 1982, Economics Program progress report forthcoming); and an interpretative review of past and ongoing research in agricultural marketing in West Africa, with a view to explain the "extractive" role of agricultural marketing (Harriss 1982, Economics Program progress report 31).

Efficiency of Marketing ICRISAT Crops

We studied the efficiency of market channels for ICRISAT crops in India by looking at market margins and market costs, as well as price correlation coefficients. Since past research gives only scanty information on market channels of ICRISAT's crops, we studied some 29 markets in SAT India and chose 3 markets in Andhra Pradesh for a detailed comparative evaluation of marketing margins and price correlations.

Average marketing and processing margins in those three markets range from 13% for pearl millet, 15% for sorghum, 21% for chickpea, and 22% for pigeonpea, to 26% for groundnuts. The lower the requirement for processing, the higher the share of the consumer's rupee the farmer receives.

Weekly price correlations in the 29 study markets showed that sorghum, pearl millet, and groundnut prices were generally less associated than prices for pigeonpea and chickpea. That reinforces an earlier finding that grain pulse trade covers longer interregional distances than coarse grain or groundnut trade does.

To test the sensitivity of correlation coefficients as a measure of the efficiency of trade between two markets, we assumed that prices were arbitrarily fixed so during alternate weeks market margins in two markets were double their actual values. Correlation coefficients

Table 12. Estimated probit results and predicted probabilities of crop failure.

Determinants of crop failure	Estimated probit coefficients	Predicted probability	Change in predicted probability, %
Constant	-1.30 (-8.69)[a]		
Village			
Aurepalle [b]		0.094	
Dokur	-0.42 (-2.67)**	0.041	-56.4
Shirapur	0.68 (6.34)**	0.261	177.6
Kalman	0.44 (4.21)**	0.189	101.1
Kanzara	-0.30 (-2.13)*	0.053	-43.6
Kinkheda	-0.51 (-3.21)**	0.034	-63.8
Year			
1975/76[b]		0.113	
1976/77	0.06 (0.82)	0.123	8.8
1977/78	0.10 (1.63)	0.134	18.6
Season			
Rainy [b]		0.177	
Postrainy	-0.56 (-8.63)**	0.068	-61.6
Soil			
Deep[b]		0.085	
Medium	0.16 (1.37)	0.113	32.9
Shallow	0.28 (2.40)**	0.136	60.6
Poor	0.48 (3.54)**	0.186	118.8
Irrigation			
Dryland [b]		0.147	
Irrigated	-0.44 (-5.39)**	0.068	-53.7
Cropping system			
Sole [b]		0.160	
Intercrop	-0.47 (-6.62)**	0.071	-55.6
Tenancy			
Owned [b]		0.083	
Fixed rent	0.05 (0.21)	0.091	9.6
Sharecrop	0.16 (2.04)*	0.109	31.3
Likelihood ratio test	381.81		

a. Asymptotic t ratios are in parentheses.

b. Refers to the binary variable of reference against which the estimated probit coefficients and predicted probabilities are evaluated. For example, the incidence of crop failure is significantly less in Dokur than in Aurepalle; a shift from Aurepalle to Dokur lowers the likelihood of crop failure 56%.

obtained by that assumption were significantly lower than from the actual price series, especially for crops with higher correlations, which indicates that correlation coefficients are sensitive to arbitrary price manipulation. So information contained in large numbers of correlation coefficients can be accepted as indicating relative pricing efficiencies across crops and markets.

Correlation of the price series of five crops among 29 study markets gave a total of more than 1000 coefficients. Their variation could be explained by at least seven characteristics of the market concerned. Correlation coefficients, and consequently market efficiency, are significantly higher:

1. the older the markets are;
2. the higher their turnover is;
3. the more telephones there are per turnover;
4. the fewer telephones there are per trader;
5. the fewer wholesale traders there are;
6. the oftener market secretaries change, and
7. the closer markets are to each other.

Market Access and Aggregate Productivity

A comparative synthesis of the various studies in the Economics Program on market access and. productivity is consistent: aggregate productivity of agriculture in India is measurably affected by market access through physical and institutional infrastructure. A series of studies at macro and micro levels arrive at similar magnitudes of the measured effects. Policy implications drawn from the studies are summarized in Table 13.

Based on a normative-activity analysis model and quadratic programming, trade restrictions between regions decrease aggregate productivity, about 2% with traditional technologies and 4% assuming improved technologies are adopted. Adopting new technologies accentuates regional differences in comparative advantage so the negative effects of trade restrictions on productivity are more pernicious.

That normative calculation does not indicate the time lag for the effect. To measure that, we did a positive analysis on food zoning in India.

Food zones were established in India during the past 20 years in different shapes and with various degrees of intensity. By creating food zones, the government establishes the monopoly right for all foodgrain trade across the borders of food zones. Our analysis showed that—*ceteris paribus*—food zoning influences aggregate productivity with a lag of 2 to 4 years; lifting trade restrictions imposed by food zones would increase aggregate productivity about 5%, which is similar to the result from the normative-activity analysis.

Apart from food zoning, other variables may constrain market access. We analyzed a data set on 94 districts over 15 years to measure effects of such market access variables as market density, road density, and food zoning on aggregate productivity, keeping all other inputs constant. Every year the districts were divided into groups representing above- and below-average productivity per person because productivity in districts above the average was generally expected to respond more positively to better market access while in districts of below-average productivity, better market access might lead to more imports, lower prices, and reduced productivity.

We assumed that all market access variables had a 2-year lag. The results were significant and show that a 10% increase in road density would stimulate aggregate productivity 2%, but only in above-average productivity districts. A denser road network would make no difference in below-average productivity districts.

Doubling organized market places (so-called "regulated markets" where a competitive price formation such as auction bidding, and standard scales and measures and price reporting are enforced) would increase productivity about *5%* in all districts. Lifting food zones would have no impact on districts of below-average productivity, but would increase productivity 4 to 7% in above-average districts.

When the effects of those variables were measured keeping all other inputs constant, the results showed quite clearly how much the various factors that constrain market access influence aggregate productivity. Among the

Table 13. Market policies and their impact on agricultural productivity in India (summary of results of four analytical approaches and different sets of data).

Approach number	Market policy measure (assumed or observed)	Quantified impact on productivity	Analytical method, applied data used, and sources of data
1	Restriction of trade flows between regions to 10% of free flows at two different levels of technology	Decrease in productivity (in t/ha) by: a) 2% with traditional technologies b) 4% with improved technologies	Normative activity analysis with quadratic programming for an interregional trade model with secondary data on coefficients and elasticities
2	Lifting of trade restrictions imposed by food zoning (keeping all other input variables constant)	Increase in productivity of foodgrains (in t/ha) by 5% after 2 years	Empirical analysis with the generalized leas squares technique on 10 years' data for 13 states in India; official statistics
3		Productivity in (Rs/ha) is affected with a lag of 2 years as follows:	
	a) Increasing road densities by 10%	a) in above average regions 2% increase in productivity; in below average regions no effect on productivity	Empirical analysis with the ordinary least squares technique and 15 years' data for 94 districts in 4 states of India; official statistics
	b) Doubling of market densities	b) in all regions increase in productivity by about 5%;	
	c) Lifting food zoning (keeping all other variables constant)	c) in above average regions increase in productivity by 4-7%; in below average regions no effect on productivity	
4	Reduction of the average distance to the nearest market from 21 to 14 km.	Increase in productivity (Rs/ha) by 3% at given constant inputs; by 9% at increased input use	Empirical analysis, with the multivariate regression technique, simultaneous equations, and data from 300 farmers; our survey

constraints, the "regulated market" seems to play a uniformly positive role, as market density has positive effects regardless of a district's above- or below-average productivity per person.

To see how access to a market affects agriculture at the village and farm level, we did an intensive marketing study in two regions, Mahbubnagar, where market density is relatively low, and Nagpur, where it is high. We selected 20 villages in each region according to distance from the nearest market. In each village we interviewed 15 farmers drawn from three farm-sire classes. Productivity was measured by monetary value of gross product per unit area at constant prices. Analyses of the data by multivariate regression techniques showed how market access and other inputs affect productivity: (a) directly by inducing farmers to allocate cropping systems to comparatively advantaged land; and (b) indirectly by affecting input use.

In the Mahbubnagar region (where distances to the nearest market average 21 km) generally small and medium farmers respond to better market access by better input use, while large farmers respond mainly by changing cropping patterns. In the Nagpur region (where distances to the nearest market averaged 14 km) large farmers did not respond to market distance, but small and medium farmers responded strongly through both cropping pattern allocations and improved input use.

If the findings from those two regions indicate a general pattern, improving market access for villages initially would be mainly to the advantage of large farms until a certain market density is reached. Then further improvement of market access provides no extra benefits to large farms, but continues to provide dividends for medium and small farms.

That finding is quite in line with the general theory of innovation: investments in improving market access should be as rapid as possible to shorten the adoption cycle during which large farmers derive most of the benefits. If implemented rapidly, investments in market access would not only increase agriculture's efficiency but also improve equity in income distribution.

Looking Ahead

We will continue to work with scientists in the Farming Systems Research Program and in national programs in four pilot on-farm verification tests of deep-Vertisol technology options in Madhya Pradesh, Karnataka, and Andhra Pradesh. Our objective will be to assist in evaluating the performance of the technology options, in designing modifications where required, and in identifying constraints in delivery systems that may impede the transfer of technology to farms,.

We expect that the availability of estimates of the elasticities of rural labor supplies with respect to wage changes will enable us to better assess employment and income distribution effects of technologies emerging from ICRISAPs research. Our assessment will be strengthened by the availability of results from a scenario analysis of market-level effects of increasing the production of the ICRISAT mandate crops.

Additionally, we plan to link our assessment work to a global model of world agriculture. Expectations by ICRISAT scientists on prospective technologies will form the basis for estimates of predicted technical change, which in turn will be one input to the models being developed in the International Institute of Applied Systems Analysis (IIASA).

With regard to risk, we plan to complete research in 1983 on the whole-farm evaluation of prospective dryland technologies, on aspects of fluctuations in rural household income, on farm-level causes and consequences of crop and field diversification, and on farm-level impact of crop insurance. We also shall bring together various research findings to comprehensively assess crop insurance in India's SAT. And we plan to start an enquiry into the formation of price and yield expectations by farmers in an upland groundnut-and-paddy-growing region of peninsular India.

Other research results forthcoming in 1983 will be based on a nutrition study in the VLS villages, a study of adoption of hybrid sorghum and pearl millet in major producing districts of

India, and an inventory of common property resources. We shall also undertake greater responsibilities during 1983 in training social scientists working in national agricultural research institutions in SAT countries.

Two conferences are planned during 1983. An international conference in October will look at several dimensions of marketing in the semi-arid tropics. A national seminar in August is to assess emerging dryland technologies and how they can be more speedily delivered to farmers in India's SAT.

Publications

Journal Articles

BINSWANGER, H.P. 1981. Attitudes toward risk: theoretical implications of an experiment in rural India. The Economic Journal 91:867-890.

JODHA, N.S., and SINGH, R.P. 1982. Factors constraining growth of coarse grain crops in semi-arid tropical India. Indian Journal of Agricultural Economics 37(3):346-354.

MURTY, K.N. 1982. Theoretical restrictions on the parameters of indirect addilog demand equations—a comment. Econometrica 50(l):225-227.

VON OPPEN, M. 1982. Toward private investment funds for development aid. Technological Forecasting and Social Change 22(2):201-210.

Conference Papers

DOHERTY, V.S. 1982. Tank irrigation in,crosscultural perspective. Presented at the Workshop on Modernization of Tank Irrigation, 10-12 Feb 1982, Centre for Water Resources, Perarignar Anna University of Technology, Madras, India.

GHODAKE, R.D., and WALKER, T.S. 1982. Yield gap analysis in dryland agriculture: perspectives and implications for the eighties. Presented at the National Seminar on A Decade of Dryland Agricultural Research in India and Thrust in the Eighties, 18-20 Jan 1982, All India Coordinated Research Project for Dryland Agriculture, Hyderabad, India.

JODHA, N.S., and MASCARENHAS, A.C. 1981. Adjustment to climatic variability in self provisioning societies: some evidence from India and Tanzania. Presented at the Meeting of the Scientific Committee on Problems of the Environment (SCOPE), 27 Sept-1 Oct 1981, Toronto, Canada.

RYAN, J.G. 1982. Discussant's comment: Socioeconomic considerations. Pages 699-715 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

RYAN, J.G., V1RMANI, S.M., and SWINDALE, L.D. 1982. Potential technologies for deep black soils in relatively dependable rainfall regions of India. Presented at the Indian Bank Seminar on Innovative Technologies for Integrated Rural Development, 15-17 Apr 1982, New Delhi, India.

SHARMA, D., and JODHA, N.S. 1982. Constraints and opportunities of pulse production in semi-arid regions of India. Presented at the Symposium on Increasing Pulse Production in India: Constraints and Opportunities, Hindustan Lever Research Foundation, 9-10 Oct 1982, New Delhi, India.

VON OPPEN, M.. and RAO, P.P. 1981. A market-derived selection index for consumer preference of evident and cryptic quality characteristics of sorghum. Pages 354-364 *in* Proceedings, International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P., India: ICRISAT.

VON OPPEN, M., and RAO, P.P. 1982. Sorghum marketing in India. Pages 659-674 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., India: ICRISAT.

WALKER, T.S., and JODHA, N.S. 1982. Efficiency of risk management by small farmers and implications for crop insurance. Presented at the Conference on Agricultural Risk, Insurance and Credit, the Instituto Interamericano de Cooperacion Agricola (IICA) and the International Food Policy Research Institute (IFPRI), 8-10 Feb 1982, San Jose, Costa Rica.

Miscellaneous

BINSWANGER, H.P., and ROSENZWEIG, M. 1981. Contractual arrangements, employment, and wages in rural labor markets: a critical review. Joint report of the Agricultural Development Council, New York, and the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India.

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 in food production and agricultural engineering (eds. R.E. Kalman and J. Martinez). Amsterdam, Netherlands: North Holland Publishing Company.

INTERNATIONAL COOPERATION

Contents

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INTERNATIONAL COOPERATION

This report covers June 1981-Dec 1982, and includes the research results of the main growing seasons of 1981 and 1982 in West Africa. During 1982, in addition to ongoing programs in West Africa, Mexico, and Syria, we began a regional groundnut program in southern Africa (Malawi) and placed in Kenya an eastern African coordinator for sorghum and millet improvement financed by the Organization for African Unity/Semi-Arid Food Grain Research and Development (OAU-SAFGRAD). ICRISAT's thrust in SAT Africa is on schedule for the decade of the eighties.

Phase III of the UNDP/ICRISAT Contract for 5 more years in West Africa began 1 November 1981, and seven scientists remained in the program. USAID continued to fund the Mali program in cereal breeding and agronomy. The IDRC-funded *Striga* program in Upper Volta entered Phase II on 1 February 1982. The International Development Research Centre (IDRC) in mid-1982 began supporting the regional groundnut project that serves SADCC countries, with a groundnut breeder posted in late 1982 and a pathologist expected to join the team in 1983.

IDRC also provided a strengthening grant to the core-financed socioeconomic studies in Upper Volta and Niger. One of the two economists based in Upper Volta moved to the Sahelian Center in Niger. The IDRC grant also provided an anthropologist in Upper Volta, initially for 2 years.

The ICRISAT Sahelian Center began operations in 1982 after the signing of an agreement by UNDP, on behalf of ICRISAT, with the Niger Government providing 500 ha of land in Sadore for the Center. With a complement of five scientists in Niamey, Niger, development of the Center began. The growing season of 1982 was the first season of research there.

The 500 ha provided ICRISAT by the Government of Niger was a bare piece of land. ICRISAT has fenced it, successfully drilled two bore holes for water, built a temporary office and storage-building complex. Texas A&M University specialists completed a detailed survey and the International Livestock Center for Africa (ILCA), a vegetation survey. Some 56 ha of that land has been developed for experimentation.

The Sahelian Center farm development committee, in its first meeting in Niger in December 1982, drafted a farm development plan. The Institute de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) deputed a senior scientist to ICRISAT to serve as West African regional coordinator. He arrived in late 1982.

The Sahelian Center will be ICRISAT's main base in West Africa for research in millet and groundnut, and on farming systems associated with those crops. It will also support other programs in the region.

The 1982 in-house review of ICRISAT African programs was held 1-5 March 1982 at ICRISAT Center.

Severe budget reductions placed on ICRISAT in 1981/82 delayed ICRISAT's long-term plan for Africa. Attempts have been made to overcome budgetary restraints with special-project financing.

Upper Volta

Sorghum Breeding

The sorghum improvement program aims to identify improved varieties that will respond significantly better than local varieties to the harsh environment (soil and climate) under moderately improved and highly improved cultural conditions.

We have tested several experimental lines identified at Kamboinse Experiment Station on a north-south axis covering a range of climatic conditions, and we have identified new selections from crosses made at Kamboinse, in addition to evaluating of finished lines and hybrids from ICRISAT Center.

Toposequence studies at Kamboinse indicated that within a rainfall zone, sorghum-crop performance is more favorable in mid-slopes (medium deep soils) and lower slopes (deep non-inundated soils) than in other arid types. With improved cultural practices and increased soil fertility, an early-maturity sorghum can escape both *early- and late-season drought on* upper slopes (shallow soils).

Research on photoperiod sensitivity is a priority in order to ensure that planting dates, governed by rainfall, are so matched with flowering dates later in the season that the flowering occurs neither too early nor too late.

Other priority characteristics include plant height of about 2 m; resistance to foliar diseases, grain mold, and charcoal rot; resistance to insects, especially sorghum midge and aphids; good stand establishment; drought tolerance; and grain with superior cooking quality.

Kamboinse village. Farmers in Kamboinse village continued for the 3rd year to test E 35-1 in plots near family dwellings. Following the recommended management practices (land preparation, fertilizer—100 kg/ha fertilizer mix N: P_2O_5,K_2O 14:23:15+22N, thinning, and weeding), 46 volunteer farmers harvested from 1100 to 3850 kg/ha for an average of 2465 kg/ha, much more than from local landraces.

Features noticed regarding E 35-1 in Upper Volta:

1. Its yields were associated with plot location when distinguishing among dwelling, village, and bush fields. Highest yields came from fields near dwellings where organic household refuse typically is deposited.
2. It yielded significantly more-than local white sorghum under improved management only on such advantaged plots.
3. In five of six paired plots where local control fields were planted after E 35-1 plantings (i.e., after 12 June), E 35-1 outyielded the locals an average 38%.
4. Under low tillage, seedling emergence of E 35-1 was significantly lower than emergence of local controls.
5. E 35-1's relatively short, late recommended planting period (15-30 June) limits farmers' flexibility to adapt to early season rainfall and conflicts with timely weeding of earlier-sown, full-season materials.
6. Farmers preferred E 35-1 to local varieties for ease of threshing and *td* quality.
7. Of 44 first-year participants, 39 planted E 35-1 in 1981, and data were obtained from 37 farmers' fields. E 35-1 yields were approximately 800 kg/ha compared with 630 kg/ha for local varieties.

Multilocational Trial

Promising entries identified at Kamboinse were grouped into three maturity-cycle groups—long, medium, and short. The long-cycle materials were tried in central Upper Volta (Kamboinse and Saria, 800 mm rainfall) and in the south (Farako-Ba, 1100 mm rainfall). The medium- and short-cycle materials were tried, with relatively late plantings, at Ouahigouya (450 mm rainfall), Kamboinse, Saria, and Tiebele (950 mm rainfall), and Farako-Ba. Population densities were around 93 000 plants/ha and fertilizer applications were moderate (42:23:14) at all plant sites.

Long-cycle trials. In the central zone, the optimum flowering date for full-season material is around 90 days (for first week of June planting), while for the south, it is around 100 days or more after planting (Table 1).

Medium-cycle trials. Eleven of the 14 entries appeared promising (Table 2) and will be used in future tests; the most promising were 9C4 TN1-20, 193-2, 19-2, NBES, and Zongo local.

Short-cycle' trials. Table 3 gives data on entries that were superior at one or more locations. Line 212-10 was outstanding at all five locations, but

Despite the relatively late planting required, sorghum E35-1 is papular with Upper Volta farmers/or its high yield, ease of threshing, and good to quality. It does best on good soils with proper management, including fertilizers.

Table 1. Grain yield (kg/ha) and days to flower (DTF) of entries in the multilocational sorghum trial, long cycle, Upper Volta, 1981.

	Kamboinse		Saria		Faroka-Ba	
Entry	Yield	DTF, after 5/6/81	Yield	DTF, after 26/6/81	Yield	DTF, after 18/6/81
75KS1 [a]	2570	83	3440	78	1600	78
Zalla	2710	91	2490	78	920	71
Okanlopieno Ogalu	1380	115	1400	101	2730	95
Niger 2573	1020	108	1800	92	1730	78
Juame Piela	820	115	1140	99	1090	91
Ouedejoure	740	126	0	-	1980	109
Kamboinse local	2510	98	3250	70	2420	68
SE	±308		±341		±207	
Site mean	1840		2110		1430	
CV (%)	29		28		25	

a. 75KS1 = 7629 x Good Grain Population.

Table 2. Mean grain yields (kg/ha) and ranks of superior entries in the multilocational sorghum total, mediums cycle, Upper Volta, 1981.

Entry	Ouahigouya		Kamboinse		Sana		Faroka-Ba		Tiebele	
SRN 4841	2000	3	3080	5	4190	9	1680	9	145	17
E35-1	2100	8	2240	15	3380	12	1300	17	860	2
193-2	2070	9	2910	9	4570	1	2700	3	410	11
37BK	2620	2	3020	7	3090	16	1730	8	850	3
SPV245	2250	6	3140	4	4340	2	1380	15	890	1
19-2	2350	5	3010	8	3680	8	1450	12	0	20
TN1-16	1630	15	3400	1	4310	4	2120	4	520	8
NBES	2420	4	3220	2	4320	3	1850	7	0	20
9C4 TN1-20	3390	1	3160	3	3330	13	2820	1	600	7
9C4 TN1-4	1980	10	2750	10	3470	10	2100	5	420	10
Zorgho local	2170	7	3030	6	4010	6	2780	2	30	16
SE	±366		±501				±272		±117	
Site mean	1920		3470		1680		1680		430	
CV (%)	33		25		21		28		47	

the outstanding performance of 80W65 (from the Striga-resistance program) in the central zone made it rank first. Other promising selections were 32-1, 27-1, and 5-2-1.

ICRISAT Center Trials

International Cooperative Varietal Trial. This trial suffered from drought at the end of the

Table 3. Mean grain yields (kg/ha) and ranks of superior entried in the multilocational sorghum trial, short cycle, Upper Volta, 1981.

Entry	Ouahigouya		Kamboinse		Saria		Farako-Ba		Tiebele	
80W65	1390	11	1520	7	5110	1	3220	I	350	9
Jan Jare	1060	14	980	14	3860	10	2890	3	0	16
SPV 35	1520	7	1500	9	3960	9	2190	10	1060	1
WA x NIG	2000	3	2310	1	2160	16	2360	8	510	5
IS 8272	1820	5	1200	13	2620	15	1600	15	310	10
5-2-1	1740	6	940	15	4310	4	2690	5	540	4
4-2	1910	4	900	3	4040	8	2300	9	0	16
212-10	2070	1	2000	2	4740	2	2770	4	770	2
32-1	2010	2	1370	11	4310	5	2380	7	490	6
9-5	1420	9	1830	4	4140	7	1930	11	540	3
SC 108-4-B x CS 541	1090	13	1600	5	4580	3	1930	12	160	12
27-1	1430	8	1530	6	4160	6	2930	2	210	11
SE	±243		±111		±288				±89	
Site mean	1450		1480		3840	"	2290		370	
CV (%)	29		30		13		21		42	

season; yields did not differ significantly ($P > 0.05$), but four lines—M36136, M36095, M36056, and M36121—appeared to be drought tolerant.

International Sorghum Drought-resistant Nursery. One line, D71258, which appeared to be drought tolerant, was outstanding throughout the season.

International Hybrid Trial-2. This trial also suffered from late-season drought so yields did not differ significantly. But hybrids 2077A x MR-729, 2077A x MR-730, and 296A x A608 produced attractive yields.

Millet Breeding

Phase II of the UNDP-funded, 5-year project ended in 1981. Progress in the first 5 years enabled us to reassess breeding objectives and the area to be covered in Upper Volta. The program now is oriented to developing varieties for the 500- to 900-mm rainfall zone with emphasis on the Mossi Plateau, which has high concentrations of arable land and population (predominantly Mossi ethnic) in Upper Volta. Varieties developed by 1CRISAT for the Sahelian region of Upper Volta should suit that region. Broad objectives of the program are to select two

An ICRISAT sorghum in an international preliminary yield trial in Upper Volta remains standing under severe drought that destroyed other sorghums in the trial.

groups of varieties with these growth habits and characteristics:

1. Photoperiod-sensitive, full-season varieties (about 140-day maturity), preferably flowering about 7 September but not later than common cultivars, which flower around 15 September. Such varieties will be suitable for sowing with the early rains (late May to 21 June) on lower slopes of the toposequence in the 500- to 900-mm rainfall zone.
2. Photoperiod low sensitive/insensitive, early-maturing varieties (80-110 days) for sowing in late June to the middle of July in the 500- to 700-mm zone and during the same period in upper level fields in the 700- to 900-mm rainfall zone. Occasionally sowing early millet with the beginning of rain as intercrop or monocrop may also be promoted with the availability of superior early-maturing varieties. We select for disease and pest resistance as well as for other characters—higher yield and yield stability under both traditional and improved management practices.

Malian Introductions

Results obtained on early-maturing material in the previous years indicated that generally they were unstable. Still some variability in stability and other characters permitted us to select more stable lines with superior agronomic and disease-tolerance characters. These have been tested for their potential as varieties for seeding late. They are also used as parents in the crossing program. Two selections, P213KS and P449KS from the Malian introductions were noted for relatively greater yield stability, good agronomic characters, and resistance/low susceptibility to major diseases. Average grain yields of P213KS, P449KS and local control in the 1981 and 1982 late-seeded trials (June 27 to July 19) at Kamboinse station were 915, 735, and 410 kg/ha. In the 1982 July-sown, farmers' field trials in the 500- to 700-mm rainfall zone, yields of P449KS and P213KS averaged 21% higher than local control averages. Both selections have good *td* quality. Among the experimental varieties tested at Kamboinse station in a 19 July 1982-sown trial, KEV 81-8 and KEV 81-1 gave average grain yields of 1180 and 1050 kg/ha, respectively (local control, 390 kg/ha). Some of the notable lines used in crossing are selections from Togo germplasm, P242, P449, P446, P213, KMDC, MPS7936, and ICMS 8204.

Germplasm Collection

A total of 1100 millet heads were selected in farmers' fields in 1980 and 1981 seasons. A preliminary description of Upper Volta millet cultivars based on collection and field observations was attempted; 24 S_1 lines were selected in 1982 based on S, progeny results of 395 lines retained from the original 1110 heads. The S_1 progenies were replicated three times as single-row plots, and one replication was screened in the downy mildew sick plot. Lines selected represent only those that had a better agronomic score in all three replications and lower disease scores for downy mildew and smut. We divided the selected lines into two sets—those flowering before 31 August and those flowering later. For each set a recombined bulk is being derived by mass recombination in the off-season from both S_1 and S_2 seeds. The newly derived population will be evaluated in 1983.

A total of 200 millet cultivars collected by IBPGR in Upper Volta in 1981 was evaluated in 1982 for agronomic and disease resistance/tolerance characters—one replication was screened in the downy mildew sick field. Entries CVP59, CVP72, CVP89, CVP146, and CVP469 had downy mildew infection indexes of less than 5%.

Crosses to Generate Diversity

Crosses and backcrosses were made and composite populations derived to generate new variability. In 1982, 33 F_3 lines were selected from 243 F_3 rows from crosses between full-season local cultivars and early-cycle exotic parents. The flowering behavior of a preponderance of lines was that of the early-maturing parent; however.

some were late-flowering segregates. A total of 180 F_3 plants of various maturities was selected.

Ten experimental varieties are being derived by recombining selections in certain maturity classes with common head characters. In addition, 260 promising selections were made from F_2 populations and composite populations.

Identifying stable sources of resistance to ergot, caused by *Claviceps fusiformis,* to use in breeding varieties that mature early has been a major concern, and encouraging results have been achieved. Continued screening since 1979 of lines from the West African collection and segregating lines of planned crosses under artificial epiphytotic conditions permitted us to identify in 1982 a few stable lines with low susceptibility (less than 5%) to ergot. Six lines from the cross SC x 700158 and another six from the entries P446, P449 and P285 had less than 5% ergot in the third round of screening under artificial epiphytotic conditions.

Striga Research

Sorghum

Several local sorghum varieties from Upper Volta and Mali were tested at Kamboinse, Nakomtenga, and Farako-Ba in *Striga-infested* fields. *Striga* incidence was satisfactory for testing at all the locations. A few Voltaic sorghum varieties, including CVS 57 and CVS 122, showed promising resistance and grain yield. Resistance of N 13 and SRN 4841 was confirmed in all 1981 and 1982 trials. Local Malian varieties called 'seguctanas' (meaning resistant to *Striga)*—Niarabougou and SG-5153—have shown good resistance and grain yield. All are photosensitive, flower in mid-September, and have useful sources of resistance, local adaptation, and grain quality. Of the germplasm lines tested, IS 2814 has shown less susceptibility and produced highest grain yield in both Upper Volta and Mauritania.

Because SRN 4841 (Framida) has shown excellent seedling establishment, vigor, and grain yield potential, it was tested on farmers' fields in Yako, Nakomtenga, and Boromo. It exhibited stable grain yield both under farmers' and improved management conditions and across all the three ecological zones in Upper Volta. And it produced highest grain yields (5000 kg/ha) in Nigeria. It responded favorably to fertilizers and improved management conditions, such as plowing. SRN 4841 will be considered for release for areas growing red sorghum in Upper Volta.

Good Keeping Quality

A handicap somewhat offsetting its excellent yield potential, local adaptation, and resistance to *Striga* is its brown seed, which is preferred for beer rather than for food, but the farmers who made *to* with SRN 4841 were satisfied because it had good keeping quality. To improve its grain color, we crossed it with white grained parents—with promising results. White-grained selection 80W68 (SRN 4841 x WABC x P3-3) produced the highest grain yields in multilocation tests in Upper Volta in 1981. Some white-grained progenies have retained SRN 4841's resistance and produced good yields (Table 4), an important achievement.

Several low-stimulant varieties, such as IS 7227 and IS 8785, have been crossed with E 35-1 to transfer resistance into it because its grain yields and quality are good when *Striga* is not a problem. Some advanced generation progenies have shown less susceptibility and higher yields than E 35-1 (Table 5). The results from 1982 confirmed the higher grain yield, good grain quality, and *Striga* resistance.

Genetic analysis of field resistance of sorghum to *Striga hermonthica* with a set of diallel crosses, generation means and line x tester analyses have all revealed the importance of additive genetic variance over dominance genetic variance in controlling *Striga* resistance. This indicates that the genes for *Striga* resistance can be accumulated and that selection is most effective in breeding for *Striga* resistance. IS 9830 was identified as a good parent both for *Striga* resistance and grain yield. Among the late photosensitive locals, Seguetana Fala was identified as

Table 4. White grain sorghum selections of crosses with SRN 4841, Upper Volta, 1981.

Origin	Pedigree	Days to flower	*Striga* (no/4.5 m²)	Grain yield (kg/ha)
80W106	SRN 4841 x FLR 101	86(23/09)[a]	229	2660
80W85	SRN 4841 x G. Grain	60 (27/08)	121	2990
80W52	23-4 x SRN 4841	86 (23/09)	110	2400
80W118	SRN 4841 x FLR 101	78 (15/09)	148	2720
80W109	NJ 1515 x SRN 4841	61 (28/08)	229	3420
80W66	SRN 4841 x SPV 105	65(01/09)	109	2340
80W114	SRN 4841 x FLR 101	67 (03/09)	82	2200
80W58	SRN 4841 x SPV 105	60 (27/08)	99	2030
80W40	(146 x 3541) x SRN 4841	80(17/09)	70	1980
80W101	SRN 4841 x FLR 101	69 (05/09)	96	1960
	E 35-1 (check)	85 (22/09)	323	1960
SE				±296
Mean			250	1960

a. Planting dates in parentheses.

good. Tetron x CS 3541 was the highest-yielding hybrid that will be advanced to F_2 for desirable segregants.

Pearl Millet

Some of the local cultivars from Upper Volta were identified as promising for grain yield and less susceptible to *Striga* in the preliminary screening. The advanced screening trial gave satisfactory results in northern Upper Volta and in pot tests. The selected entries were P2627-1-19, P449-1-29, and Inbred 5258-1-19 (Table 6). Unfortunately the highest-yielding entries (in the absence of *Striga)* such as P2627-2-11 and P2627-2-18, were susceptible to *Striga.* The tol-

Table 5. Selections from crosses between E 35-1 and low-stimulant sorghum varieties, Upper Volta, 1981.

Origin	Pedigree	Days to flower	*Striga* (no/4.5 m²)	Grain yield (kg/ha)
80W146	IS 8785 x E 35-1	78(15/09)[a]	76	1180
80W144	IS 8785 x E 35-1	75 (12/09)	104	1250
80W145	IS 8785 x E 35-1	76 (13/09)	147	1470
80W134	IS 7227 x E 35-1	73 (10/09)	143	1230
80W3r3	SRN 4841	73 (10/09)	127	880
Checks				
E 35-1		86 (23/09)	297	840
Local		88 (25/09)	244	260
SE				± 696
Mean			180	1180

a. Planting dates in parentheses.

Table 6. Performance of selected millet cultivars in advanced millet *Striga* trial, Upper Volta, 1981.

Origin	Pedigree	Overall grain yield (kg/ha)[1]	Mean no. of *Striga* (Aourema)[2]	Mean no. of *Striga* in pot expt.[2]	Killed in pot expt. (%)[3]	Days to flower	Plant height (cm)
Less susceptible lines							
82S-123	P2627-1-19	950 (7)[4]	3.08 (3)	1.20 (1)	29 (3)	67	157
82S-129	inbred 5258-1-19	860 (13)	4.20 (8)	1.40 (2)	33 (6)	64	177
82S-124	P449-1-29	600 (10)	2.34 (2)	1.37(4)	33(5)	66	142
High yielding lines							
82S-138	P2627-2-11	1360 (1)	5.23 (12)	3.17(19)	57 (14)	68	165
82S-133	P2627-2-18	1240 (2)	5.43 (14)	1.99 (5)	67(18)	66	175
82S-137	P2661-3-7	1170 (3)	6.85 (16)	3.06 (16)	57 (16)	67	170
	Local	1130 (5)	3.36 (4)	3.51 (20)	100 (20)	69	163
SE		-		±1.211	-	±4.1	±20.0
Mean				2.37	-	66	155

1. Mean over five locations.
2. Square root (x+1) transformation used.
3. Number of plants killed as percentage of total number of plants.
4. Figures in parentheses are rankings.

An ICRISAT sorghum doing well in Cameroon, Africa, despite severe **Striga**, *a parasitic weed whose blossoms show at the base of the sorghum plants.*

erant lines were P2661-3-5 and Inbred 5237-1-14. Serere 2A-9-2-27 continued to show moderate resistance.

International Cooperation

The *Striga* project in Upper Volta has a regional responsibility, and organizes International *Striga* Observation Nurseries each year, in several interested African countries, including Mali, Mauritania, Gambia, Ghana, Niger, and Cameroon in West Africa and Sudan, Ethiopia, and Kenya in East Africa.

The ICRISAT *Striga* program has contributed significantly to African countries by supplying Striga-resistant sorghum varieties. N13 and SRN 4841 have stable resistance, and N13 is being considered for release in Striga-infested areas of Ethiopia, as are IS 9830 in the Sudan and SRN 4841 in Upper Volta.

Agronomic Research

A 3-year trial comparing various treatments and practices to control *Striga* concluded in Yako in

1981. A pearl millet + cowpea mixture in rotation with sorghum best reduced *Striga* infestation and increased grain yield of sorghum.

Good management seems to increase *Striga.* In a trial that compared traditional management (no plowing and no fertilizer) with hand plowing and incorporating 100 kg of fertilizer, *Striga* emergence increased with the latter practice. This was confirmed in 1982. But with a resistant variety Framida (SRN 4841), grain yields doubled with only a moderate dose of 14 kg N. The same rate of N increased *Striga* in a susceptible variety.

Sorghum and Pearl Millet Agronomy

We carried out agronomic studies in Upper Volta in collaboration with the Royal Tropical Institute, Amsterdam. In 1981 sorghum cultivars 38-3 at Kamboinse and SPV 35 at Djibo (Sahel) outyielded the other varieties, confirming our earlier observations that it should be possible to transfer superior varieties (both local and improved) mainly in east-west rather than north-south directions.

In 1982 in a preliminary trial, we identified 82S-45, 82S-47, and 82S-50 for high yields, partial photosensitivity, and *Striga* tolerance. But their dense panicle type invites grain mold and head bug problems, and their dense foliar structure makes them less suitable for intercropping.

Our toposequence studies in 1982 confirmed the relative yield stability across land types of SRN 4841, though it suffered some stalk rot on lowlands and lodged somewhat on uplands. As in 1981, 940 S was most responsive to land types and management (density), but was also the highest yielder on the drought-prone upland soil.

Our results in 1982, with improved millets (mostly short cycle), again as in 1981, were disappointing in both early and late plantings. It appears that millets that flower within 60 days are of little value in the Sudanian zone, unless a suitable cropping system can be proposed. Scattered evidence indicates that potassium may be a key element limiting millet yields and millet's responses to increased plant density.

Intercropping

Our studies in 1981 on cropping systems in response to agroclimatic zones revealed that in the high-rainfall (>850 mm/year) zone under a long season, a cereal/cereal intercropping system, following staggered (3 or 4 weeks) plantings, is common on all land types. But in the intermediate-rainfall (550 to 850 mm) zone, the diversity in cropping systems decreases and crop adaptation to different toposequence land types becomes progressively more important. Nevertheless, cereal/cereal intercropping can still be highly profitable, as shown by our results from maize/sorghum intercropping at Kamboinse, provided both crops are planted simultaneously. Likewise cowpeas and cereal crops are planted at the same time in Central Upper Volta.

In the lowest rainfall (<550 mm) zone millet, with cowpea added later, often prevails. Sorghum is grown as a minor crop on narrow strips *of* land along the swamps.

Cereal/legume intercropping. The aim of the sorghum/cowpea intercropping experiments has been to maintain sorghum yields at sole crop levels while introducing the stabilizing effect of a cowpea intercrop.

Our 1981 experiments suggested that this system is particularly relevant for uplands and midslope lands, since cowpea does not respond well to wetness or to increased cereal populations. On the dry and nutritionally poor upland soils, a cowpea intercrop may have several advantages, such as erosion control, nitrogen fixation, and possibly fewer sorghum pests. But the competitive cowpea effects on sorghum in the cowpea intercrop were particularly strong on upland soils, thus dictating a rather low cowpea intercrop density (2000 to 5000 plants/ ha for the local, spreading cultivar).

Through our 1982 sorghum/cowpea intercropping studies, which were carried out along the toposequence, several intercropping factors were confirmed. As in 1981 with maize, a cowpea intercrop With 940 S or SRN 4841 sorghum increased sorghum grain yield when the sorghum was planted at high density (80000 plants/ha) on lower slopes. But on the dry uplands, and particularly for low density, widely spaced sorghum plantings, cowpea intercrops of 5000 and 20000 plants/ha decreased sorghum yields substantially.

Different plant type needed. These results indicate a potential of sorghum/cowpea intercropping for improved (different plant type) sorghum varieties and the need to modify the cropping system to match cereal plant type and management level (plant density and fertility). Farmers do not favor a high-density cowpea intercrop because of reduced cereal yields, maintenance problems, and risks of increased cowpea *Striga.* A low density (2000 to 5000 plants/ ha) of a local spreading cowpea has satisfactorily protected the soil and reduced soil crusting.

Cereal/cereal intercropping. Consistent yield advantages of about 30% were again obtained from intercropping sorghum with early maize. The greatest advantages with SRN 4841 sorghum and maize (45%) were on upper slopes, and with local sorghum and maize on lowlands (60%); 940 S sorghum was an ineffective intercrop because of its dense, leafy plant type. The results showed greater yield stability, particularly of sorghum across land types in an intercrop rather than the sole crop.

With the sorghum/millet intercrop system, competition for nutrients (nitrogen, phosphorus, and potassium) reduced yields of both crops, with sorghum suffering most. As suggested by farmers, relay planting immediately after usual early-season drought can be more successful and provide a logical use of downy mildew resistant, early-maturing, improved millets.

Our 1982 sorghum/cowpea intercropping studies, carried out along the toposequence, confirmed cowpea's varied influences. As in 1981 with maize, a cowpea intercrop increased grain yields of 940 S and SRN 4841 sorghums when they were planted at high density (80000 plants/ ha) *on* lower slopes. But on dry uplands, and particularly with widely spaced sorghum plantings, cowpea intercrops of 5000 or 20000 plants/ ha decreased sorghum yields substantially.

Soil Fertility Management

To test implications of the information from agronomic and intercropping trials on long-term soil fertility under a permanent farming system, we initiated a long-term rotation x fertilizer trial in 1981 at Kamboinse. It combines four 2-year rotations (one based on cereal/cowpea intercropping) with two fertilizer treatments. Both rotations allow annual evaluation of residual effects.

In 1982 the largest fertilizer response again was recorded by sorghum. Positive residual effects, mainly of rock phosphate, were associated with sorghum and cowpea; a negative effect with millet. Millet responded more than sorghum to cowpea as a preceding crop in the rotation. Cowpea in rotation with cereals clearly reduced N-fertilizer requirements of the cereals. Soil analyses indicated that cereals lowered soil potassium even with a fertilizer whereas soil phosphorus content increased with applied fertilizer.

Soil and Water Management

Initial planning of the soil and water management program was completed in 1981/82. Research projects were initiated in four categories: (1) basic research at Kamboinse Experimental Station with techniques for microcatchment of water to evaluate flat plantings, contour ridges, tied ridges, and crop residues (mulching); (2) collecting soil-survey and hydrologic-survey data at villages near Yako, Djibo, and Boromo to help design and carry out water harvesting and soil conservation projects; (3) acquiring animal traction equipment and designing methods to construct and maintain hydrologic projects; and (4) collecting and analyzing hydrologic response information to develop plans and simulations of soil and water management systems.

Straw mulch applied to the surface significantly improved yields. The traditional method of planting on flat, bare surfaces restricts yields.

Plowing before planting increased yields more than 200%, and using tied-ridges with mulch increased yields as much as 500%. Four varieties of sorghum and millet responded significantly to straw mulch irrespective of soil-surface treatment. But E 35-1 sorghum responded more to water management than the local sorghum; among millets, Souna-3 responded more to water management than either Ex-Bornu or local millet.

During rainfall, straw mulch improved infiltration by reducing raindrop impact and increasing termite and other biological activity. No puddling or muddy water was observed in mulched plots. Increased biological activity, started in mulched plots immediately after the first rainfall, increased the macro-pores at the soil surface so infiltration increased greatly. Additionally, no weeding was necessary when mulch was used at planting, and only one weeding was needed in the tied-ridge plots. Otherwise, two weedings were necessary. The sorghum produced 1450 kg/ha of dry matter and the millet, 4760 kg/ha. Sorghum E 35-1 had a plant index of 2.6; millet Souna-3, 1.6.

Satellite Photographs

Aerial and satellite photographs were used to determine drainage basins and soil classifications for each area in the hydrologic surveys. Soil pits were evaluated during 1981 to verify some of the classification maps.

We plan to use animal traction in constructing water storage structures, conveyances, terraces and ridges, roads, and domestic and stock-water facilities. We will use the equipment in designing and carrying out village and field layouts to harvest water and for zero-runoff projects. Extensive personnel training now is under way with both oxen and donkey traction equipment. Equipment of the "Tropicultor" and "Nikart" types has been purchased and their design is being improved so we can construct and modify ridgers and earth-moving equipment to harvest water.

Rainfall-runoff models for computer simulation of hydrologic characteristics of drainage basins and village areas have been initiated, with plots being constructed so we may relate soil-surface treatments and crop residues to runoff volume and soil erosion. The data will be used to calibrate and verify simulated hydrologic processes.

Economics

Senior staffing in the West Africa economics program was completed in mid-1981 with the addition of a social anthropologist. The program also reached full geographic scope when we expanded research into the major agroclimatic zones of the West African SAT with two study villages representing each zone: northern Guinean, Sudanian, and southern Sahelian.

We began baseline studies in the new areas in 1981 with 150 participating farmers providing weekly information on production, marketing, and food consumption. In 1982, we initiated an integrated program of on-farm experiments involving both researcher-managed trials and farmers' tests in each of the six villages.

The farmers managed their tests of intensified cereal/legume intercropping and of improved sorghum and millet varieties. The *Striga*-resistant sorghum, SRN 4841, outyielded local controls 40% (average) in farmers' tests under traditional or moderately improved management when rainfall exceeded 700 mm. The farmers were impressed by SRN 4841's seedling emergence, wide adaptability, and response to improved management. It will enter stage-two farmers' tests in 1983.

We need data from the farmers' tests to assess financial and economic returns in cereal production before recommending fertilizer (14:23:15) for cotton. That fertilizer mixture is the most widely available in Upper Volta.

Fertilizer Returns Vary Widely

Financial returns were highest for fertilizer applied to sorghum in the northern Guinean zone (80%), dowh to 40% in the Sudanian zone, and negative in the southern Sahelian zone on millet, their dominant cereal. Returns on fertilizer were consistently higher for improved than for local varieties. Despite the profitable average returns from fertilizer in the Sudanian and northern Guinean zones, chances for financial losses exceeded 40% for local sorghum. So fertilizer is a high-risk investment in cereal production.

Valuing fertilizer at its economic cost (market plus 49% for the government subsidy) showed fertilizer as a good investment only with improved sorghum varieties in the northern Guinean zone or on lowlands in the southern Sahelian zone.

We need more studies to determine the economic levels of nutrients for cereals under various agroclimatic and management conditions.

Cereal/legume intercropping in farmers' tests required significantly more labor for planting and first weeding when cowpeas were increased from (2000-5000 plants/ha) to (5000-11 000 plants/ha). Potential gains from intensified cowpea intercropping need to be weighed against losses caused by delayed planting and first weeding of other crops. Our analysis showed that cowpea densities on farmers' intercropped fields approached the optimum.

Analysis of baseline survey data obtained in the Sudanian zone during 1980 focused on crop budgets and evaluating donkey-traction systems. We drew three conclusions: (1) That returns per hour offamily labor explain resource allocation better than do returns per hectare. Millet's return/ha is inferior to white sorghum and groundnut, but superior for returns per hour of labor. (2) Official prices had no effect on crop production. There was no attempt to enforce official prices, so raising official prices to market levels would not influence production. (3) Economic returns were lower than market price returns. That is, crop production in the sample was overvalued by international prices so shifting domestic prices to international prices might reduce production.

Finally, we completed a study using decomposition techniques to examine the effect of light donkey-traction systems on labor use, land use, yields, and cropping patterns. Households with traction equipment cultivated larger areas and had higher gross income, but hand-tool farms produced higher gross and net income per hectare, and total net farm income. Due to area expansion alone, traction households used 18% more total farm labor than did hand-tool households.

Anthropology

Anthropological studies were added in July 1981 to the ongoing research of the West African economics program. Research begun in the six Upper Volta study villages that year is being extended to Niger in 1982/83.

The anthropologist's task in each village is to assess the causes and rates of social and economic change by considering such large-scale phenomena as the effects of population growth and environmental deterioration, and by studying adoption rates of introduced technologies and cultivars and any resulting repercussions.

A comparative study of land tenure and inheritance systems is uncovering important variations related to ethnicity and village settlement history. In all ICRISAT villages, despite their differences in rainfall, local history, and geography, the pattern of land tenure seems to be changing with increasing populations. The intensity and duration of soil exploitation also are changing as are preferred crop varieties.

Ethnology of the fanning system. A further aspect of the studies is analyzing status and wealth differences among households, and how the differences influence management, decision making, and acceptance of innovations on family farms. The research, with the work on socioeconomic change, is providing insights on adopting ox-drawn plows, donkey carts, and bicycles in rural communities.

Each farm has several intensively cultivated fields a few moments' walk from the habitation. By contrast, "bush" fields, up to 10 km away, are characterized by long-fallow and shifting cultivation with little or no applied fertilizer. ICRISATS sample farmers in Koho village, for example, have adopted oxen, plows, and animal traction rather rapidly since 1975 but at different rates: oxen sooner than plows, plows sooner than animal traction. The remaining time lag is to learn to manage the plows and oxen together.

In some areas donkey carts make it possible to apply manure to the more distant fields, thus maintaining fertility and yields. In other regions, where less manure is available, farmers have begun to use chemical fertilizers. More intensive cultivation on the bush fields is further aided by another introduction—the bicycle. By reducing travel time, bicycles permit farmers to spend more time tending distant fields.

Adding an ox-drawn plow permits a farmer to increase the area cultivated. As competition for the remaining land increases, farmers who can afford plows, carts, bicycles, and livestock may control more and more land to the detriment of poor farmers. By developing less expensive, more versatile farm equipment, and perhaps alternative agronomic techniques to increase yields, ICRISAT may help the poorer farmers catch up with the entrepreneurs.

Determinants of labor availability. Labor shortages during peak agricultural periods may be a major constraint on crop production in West Africa, where family members (Fig. 1) rather than hired labor, do the crop work on most farms. To discover factors responsible for labor shortages, the ICRISAT anthropologist is assessing: (1) malnutrition and disease during the "hungry season" (Fig. 2), (2) seasonal and permanent out-migration, and (3) the demands of economic activities other than crop work.

To supplement the research on labor supply, and to balance the economist's study of farm production, we launched a study on patterns of

Figure 1. A four-generation family portrait in Upper Volta where family labor helps determine crops planted, weeding times, and harvest dates and, thus, influences the adoption of improved methods.

Figure 2. Child being weighed in the "hungry season." All members of households participating in the Upper Volta village studies are weighed four times a year; the weight data and information from weekly interviews on food consumption and illness are used to strengthen ICRISAT work in Africa.

household food consumption, including quantities and sources of foods prepared daily. Preliminary data show that farmers' own crops sustain them from harvest to harvest. Even during the preharvest period, when shortages are most likely, 80 to 90% of the cereals consumed were home-grown and 84 to 91% were sorghum or millet (Tables 7 and 8).

The food consumption studies will help assess the palatability, milling, and baking qualities of new cereal and legume varieties developed by ICRISAT and introduced in farmers' tests.

Table 7. Percentages by origin of cereals consumed during the dry season in two ICRISAT study villages in Upper Volta, 1982.

		Origin of cereals consumed		
Village	Village population	Home grown	Purchase	Exchange
Kolbila	1321	90	8	2
Koho	1272	78	6	16

Mali

The ICRISAT-Mali cereal breeding program and the sorghum-millet improvement program of the Malian Food Crop Research Service (SRCVO) were fully integrated in 1981. The ICRISAT-Mali breeder and technicians are to support the national program with technical advice and day-to-day "teaching by doing."

Sorghum Breeding

We have attempted four strategies to identify high-yielding sorghums: (1) exploiting Malian varieties, (2) introducing promising sorghums from other countries, (3) exploiting F_1 hybrids, and (4) using hybrid derivatives.

Table 8. Types of cereals consumed (percentages) during July and August (before harvest) in three Upper Volta villages, 1982.

Village	Village population	White/red sorghum	Millet	Maize	Rice	Fonio
Oure (Southern Sahelian)	775	10	86	-	2	2
Kolbila (Sudanian)	1321	85	10	5	-	-
Koho (Northern Guinean)	1272	91	3	6	-	-

Two Kenike sorghum heads (left) contrasted with the group of upright heads on ICRISAT sorghum AT x 623 x CMS 306 near Cinzano, Mali, West Africa, where plants must withstand harsh environments to survive.

We have used several locations and latitudes in Mali to evaluate the complete Malian sorghum collection of 1204 accessions. Yield tests of the most promising accessions in 1981 and 1982 let us identify two varieties, CSM 387 and CSM 332, that yield 15 to 25% more than the present variety when rainfall exceeds 1000 mm a season. Both new varieties are proposed for further station and farmer testing in Mali. Both varieties also have been used extensively as parents in our population breeding program.

After testing hundreds of introduced sorghum varieties during 4 years in both observation nurseries and yield trials, we have little hope of finding a variety we can introduce directly to farmers. The biological problems are principally leaf diseases (sooty stripe and anthracnose), stalk rot (charcoal rot), and lack of drought resistance.

Because they lack seedling drought tolerance, exotic sorghums often produce poor stands. And drought during grain fill leads to soft chaffy grain. Local Guinean sorghums produce hard vitreous grains under the same conditions. Additionally, Malians do not like food from many introduced sorghums, so we now have tests that let us predict food quality and use only small quantities of breeders' seed.

Redlan Resists Leaf Diseases

Our experiences with F_1 hybrids and introduced varieties have been similar. Nearly all of the seed parent lines are introduced and their F, hybrids often carry the same defects as the female parent. But BT x 378 (Redlan) is a happy exception. That well-known American variety has good leaf disease resistance and sets hard seed under post-floral drought. Unfortunately its seed is red and its panicle is small and compact, but we are using it extensively in our crossing program.

Using selected exotic and local parents, we made 58 crosses from which we evaluated 208 selected F_3 lines in 1982. If one parent is susceptible to sooty stripe, the susceptibility is additive. Then under severe disease pressure all F_3 progeny from a susceptible parent are infected, except for crosses made with BT x 378. It is resistant, so with a disease-resistant Malian parent we have both parents resistant.

Using a "male-sterile facilitated recurrent selection" scheme, we have made rapid progress with our sorghum breeding populations, which now include Malian Guinean sorghums, a Senegalese Hegari (Hadien kori), a Senegalese variety (CE 90), and much elite breeding stock from ICRISAT Center. After the first selection cycle, we generated 550 F_4 lines, evaluated them at three locations in 1982, and identified four lines with resistance to both leaf disease and long smut. One line had only a restricted lesion-flecking reaction to sooty stripe so perhaps it can be used for horizontal resistance. In addition one line had uniform long cylindrical panicles and excellent grain quality. Since it was susceptible to leaf disease, it is being crossed onto its disease-resistant sibs.

In addition to the base population, we have a derivative population with N-13 (*Striga* resistant) as the male parent. The second cycle of the population was grown in a farmer's field heavily infested with *Striga* in 1982. From his field we selected 25 plants that showed no stress or *Striga*.

Sorghum Agronomy

We used a factorial experiment to compare CSH-5, CS 3541 (male parent of CSH-5), and a selected local. While CSH-5 apparently was more agronomically responsive than the local throughout much of the cropping season, late-season drought stress caused extensive lodging and poor grain fill by CSH-5. Grain yields did not differ (2090 kg/ha for CSH-5 and 2020 kg/ha for the local) but grain quality of the local was superior.

Cereal/cereal intercropping. Sorghum and millet were compared as intercrops with maize. Both systems are practiced to some extent locally. In a factorial experiment, we varied intercrop density, intercrop seeding period, and nitrogen application rates at three locations: Cinzana, Sotuba, and Sikasso. Rainfall ranged from just over 500 mm at Cinzana to about 1200 mm at Sikasso.

While response patterns varied from site to site, some situations gave large yield advantages without compromising the main cereal crops, particularly in the higher rainfall regions. In Sikasso, millet averaged 860 kg/ha with 1800 kg/ha of maize, a potentially rewarding combination. We will continue this experiment.

Sorghum/millet intercropped with cowpea. Modifying the sorghum/millet cropping systems remained elusive. Our factorial experiment this year compared effects of two cowpea varieties on sorghum or millet. We planted the cowpeas (1) the same time as the millet or sorghum, (2) about 2 weeks later, and (3) about 4 weeks later, at three densities (12500, 25000, and 50000 plants/ha). Cowpea harvests were after 60 days, 80 days, and the end of the season.

When cowpea hay yields went up, cereal yields generally went down and vice versa. Early cowpea harvest tended to maximize cowpea hay yields and minimize losses in cereal yield. In some cases, cowpeas harvested early stimulated cereal yield. That is encouraging, even though satisfactory harvest and storage technologies are not yet available for an early cowpea hay harvest.

Topographic sequence. A new experimental design allowed us to compare crop performance at several densities and fertility levels in several soil types along the catina at Cinzana and Barmendougou. Crop x fertility, crop x density, crop x soil type interactions, and 3rd order interactions gave us a clear picture of crop performance across and within soil types, and effects of agronomic treatments within and across soil types.

We thus compared several cowpea varieties.

The noteworthy result, other than the statistical methodology working, was lack of response to phosphorous on most of the soil types at both locations.

We shall test the stability across and within soil types of new sorghum and millet varieties from the breeding program.

Semi-arid zone research station development (Cinzana). After more than 5 years, the Cinzana Research Station was formally inaugurated in July 1982. About two-third of the station's 100 ha was either in crops or plowed for next year's program.

Soil samples taken last year were analyzed at the Sotuba laboratory, with a subsample sent to Texas A & M University for analysis.

We are using aerial photo mosaics to make soil and topographic maps after the Institut Geographique National (IGN) photographic mission in December 1981; the 3-band data taken during the mission permit us to make false-color images. Using the 3-band data and existing computer programs, we are planning extrapolations from existing and future soil and other ecological and crop production data.

Training

National Center for Agricultural Mechanization. Training programs on operating animal traction and motorized farm equipment are under way at the National Center for Agricultural Mechanization. The training includes animal husbandry, smithing, and welding. A simplified toolbar is being built by the trainees. We are thoroughly testing the Nikart tool carrier and rebuilding our Boyer tractors. Prototype toolbars and clamps are being fabricated as a part of the training.

The training program is carried out jointly with staff of Machinisme Agricole, the HELVETAS training team, and ICRISAT.

Thesis students. Several Malian universities require final-year students to write a thesis, and students from several institutions have written theses based on work with us, reporting on strategies to intensify millet production, N-fertility x density, technical and economic aspects of intercropping, cereal intercropping, weeding methods, a herbicide x weeding tool, criteria for selecting millet, and characteristics of guinea sorghums. Their studies create an important link between our research and the Malian university community for long-term research benefits in Mali.

Graduate studies. ICRISAT/USAID/Mali is funding three Malian graduate students in the U.S. We attempt to dovetail graduate students' activities with Title XII activities. Thesis research is oriented toward Malian problems.

Sorghum Physiology

Because photoperiod sensitivity permits a range of planting dates while maintaining flowering at the end of the rainy season, we are breeding photoperiod-sensitive sorghums. In 1981 and 1982 we studied photoperiod sensitivity by covering seedlings (starting 15 days postemergence) 11.2, 11.4, 11.8 and 12.0 hours daily, and left the control uncovered. So long summer days would not induce flowering in a "short day" species like sorghum, we planted the nursery in May. Malian varieties (CSM varieties), all photoperiod sensitive, differ in sensitivity. Those from U.S. seed parent-line AT x 623 are sensitive but intermediate between the parents.

With a wheel or spoke-design experiment and a 3000-watt light at the hub, we determined the relationship between light intensity and photoperiod response. The design will let us detect and screen for photoperiod-sensitive sorghums, and the additive inheritance of photoperiod sensitivity will let us select for any response we want from full-sib combinations.

Millet Breeding

Failure of introduced pearl millets has exceeded that of introduced sorghums. The millets are highly susceptible to mildew and have spindly stems.

In 1981 we made many full-sib crosses

between 12 selected Malian local millets, C1VT from Niger, Souna III from Senegal, and INIADI from Togo. Then we grew the F_1 hybrids in 1982 at four locations. The F_1s indicate that the largest heterotic responses come from Souna Sud, Toromio, Sanio, and CIVT as observed in other West African programs.

Future selection will be more efficient as we screen materials for seedling vigor and downy mildew resistance at our new, irrigated, screening nursery at Koporo-Keniepe.

Millet Physiology. At Kopori in 1982 we modified a high-temperature screening procedure worked out at ICR1SAT Center. We raised soil temperatures from 35.5° at 1400 hr to 57.5°C with a covering of charcoal dust, which gave clear varietal differences in ability to withstand high temperature and drought. The local Koporo variety, NBB, performed best.

As blowing sand hinders seedling establishment, we devised a "burial" technique of planting seedlings 2 cm deep, adding 1 cm of sand the day they emerge and another 4 cm of sand 7 days later. Plant survival at 18 days was like that in the high temperature experiment, but with much wider differences. We plan to use the "burial" technique routinely as we select segregating progeny.

Millet Pathology. The Senon Plain area of Mali, where Koporo is located, is one of the most important millet-producing regions of West Africa, but downy mildew is a perennial, severe problem. We estimated yield losses to downy mildew in farmers' fields at 30% in 1982. Our

Because seedlings often must withstand blowing sand in Africa, ICRISAT scientists devised a technique of planting millet 2 cm deep, adding 1 cm of sand the day seedlings emerge, and another 4 cm of sand 7 days later. Wide differences in responses to the technique make it valuable in breeding programs to segregate progeny.

estimate was based on surveys in four farmers' fields, downy mildew evolution, grain harvest from each plant hill studied, and a regression equation.

The 30% corresponds with 35 to 42% yield loss to downy mildew in our earlier field trials.

Niger

Pearl Millet Breeding (Maradi)

Our experimental varieties showed stability during the 1981/82 crop year across African countries. ITV 8004, ITV 8002, and ITV 8001 were stable in Niger, Nigeria, and Senegal and ranked first, fourth, and sixth in the Pearl Millet African Regional Trial (PMART). In an initial field evaluation of 25 experimental varieties, 8 of them yielded from 6.3 to 28.5% more than CIVT, the improved variety recommended for Niger, and we will further improve their potential in the future.

During 1981 we contributed 16 experimental varieties and lines for testing across countries in the pearl millet exchange nursery.

Although 1981 rainfall started late and totaled less than normal, its distribution through the cropping season was good, except in Niamey and in the eastern and northern parts of Niger where the season ended in drought.

Despite late, inadequate rainfall in 1982, experimental varieties that we developed were widely tested in regional and national trials: in Senegal, Mali, Upper Volta, Nigeria, Cameroon, Sudan, and in the Pearl Millet African Regional Trial coordinated by ICRISAT. ITV 8001 and ITV 8003 were widely tested in multilocation trials coordinated by the Institute of Sahel in several Sahelian countries.

In another multilocation trial that included six places in Niger and one each in Senegal, Mali, Upper Volta, Nigeria, Cameroon, and Sudan, eight of our experimental varieties were compared with CIVT and the best local control at most locations. Three of our entries—ITV 8002, ITV 8004, ITV 8001—proved superior. ITV 8202 averaged 1300 kg/ha over nine locations.

In addition to our organizing millet breeding work and trials at Maradi and other locations in Niger, ICRISAT-Niger's cooperative program coordinated the Pearl Millet African Regional Trial (PMART) and the Pearl Millet Exchange Nursery (PMXN) in 18 locations in the major millet-growing countries of Africa.

Pearl Millet Breeding (Niamey)

The primary objective of the breeding program at ICRISAT Sahelian Center, Niamey, is to generate and disseminate genetic material to national programs to ensure higher and stable yields in the region.

Important factors that prevent high yields in the southern Sahelian zone are uneven plant stands due largely to sand storms and high temperatures when plants emerge, downy mildew, shibras (a wild relative of millet with weedy growth), and two insect pests, *Raghuva* and *Acigona.* Identified disease and insect resistance can be incorporated into the breeding material. Photoperiod response, an essential component, probably interacts with potential available soil moisture to provide the needed resistance until millet matures.

During 1982 more than 900 germplasm accessions representing African collections were evaluated and seed were multiplied as S_1 bulks for 320 accessions. Expression of West African germplasm was good at Sadore, where 40 accessions were identified for possible use as parental material.

A wide range of parental material for exotic x local crosses and F_1s, segregating populations, and backcross F_1s (>1800 entries) was grown. Several superior combinations were identified for agronomic worth and freedom from downy mildew. The superior combinations will be base material for synthetics and populations. During the year, materials originating from Nigeria, Niger, Mali, and Senegal were outstanding.

Potential cytoplasmic male-sterile lines at various backcross stages and geographic origins indicated five groups with potential to be bred into seed parents.

With the idea of eliminating the weedy shibras

Table 9. Mean, variance, and range for five characters of half-sib families of Sadore Local pearl millet, 1982.

Character	Mean	SE	Variance	Minimum	Maximum
Days to 50% bloom	68	±0.2	20.7	58	75
Plant height (cm)	251	±1.2	406.8	185	307
Ear length (cm)	73	±0.4	48.2	53	92
Downy mildew (%)	10	±0.5	90.9	0	58
Shibras (%)	6	±0.4	43.3	0	37

and downy mildew, we evaluated 300 half-sib progenies and selected 63 S_0 plants to grow S_1 progenies to generate experimental varieties and half-sibs for the next cycle. Mean incidences of shibras and downy mildew were 6% (maximum 37%) and 10% (maximum 58%), respectively (Table 9).

Ten international and regional trials (462 test entries) and two exchange nurseries were evaluated to identify high-yield potential and resistance to diseases; 33 entries from the trials and 10 from exchange nurseries were retained for reevaluation in 1983. We hope to improve downy mildew resistance and retain earliness using ICRISAT varieties and S_1 selections.

Harvest index estimations in 1982 showed Sadore local at 20% compared with around 27% for CIVT and ITV 8002 and more than 30% for ICRISAT varieties and hybrids.

Pearl Millet Pathology

In 1981 the pathology program concentrated at the AGRHYMET site on the banks of the river Niger in Niamey. Material planted included the International Pearl Millet Downy Mildew Nursery (IPMDMN), the International Pearl Millet Smut Nursery (IPMSN), the International Pearl Millet Ergot Nursery (IPMEN), and the West African Mildew Differential Trial (WAMDT). In addition, we monitored development of diseases on other millet material planted at AGRHYMET and in farmers' fields.

Disease Surveys

Surveys of millet fields were conducted toward the end of the 1981 cropping season, principally along roads radiating from Niamey and on the ICRISAT experiment station at Sadore'. We also recorded stage of growth, stand density, use of manure, intercropping, and incidence of other diseases and *Striga.*

The mean incidence of downy mildew for all samples was 19.6%; the mean for the Sadore site was 35.5%, so it should be a satisfactory environment for screening against downy mildew.

Smut infections were moderate to low and blast and ergot were low in the areas surveyed. No rust was observed in any crop.

Striga infestations were low in the Niamey area but higher in areas to the east, notably between Birni Nkonni and Tahoua and between Maradi and Zinder. A notable feature was the many shibras in plantings.

One West African and seven international millet disease nurseries were planted with 571 entries in 1982.

Other plantings included a high-intensity, disease-screening nursery, two trials on fungicidal control of downy mildew, and several blocks of disease-susceptible lines for seed multiplication and spread of disease. Pots of millet "seeded" with powdered oospore material were grown as disease spreaders.

Onset of rains in 1982 was erratic and late. We used the first small showers 17 and 26 June for limited trial plantings. Burrowing rodents, overnight, ruined some 3500 of 4000 pockets of newly planted grain. Thereafter, daily baiting with grain treated with an anticoagulant (Coumafene) protected new plantings.

Infector material was planted 30 June and 1 July, as were the fungicide trials. After an 8.7-mm shower 11 July, IPMEN, MLT, PMART, and part of the Pre-IPMDMN were planted 17

July. Then we ceased planting for more than 3 weeks, waiting for moisture until 3 August. Plantings were completed 6 August, and fungicide trials were replanted as the first ones had failed.

The West African Regional Disease Evaluation Nursery (WARDEN), which assembles West African material thought to be disease resistant, had the following entries: Maradi, 18; Samaru, 31; Bambey, 10; Kamboinse, 3; Bamako, 3; and Niamey, 3.

Development of Diseases

Downy mildew. Susceptible millet planted in pots at Sadore 28 May showed downy mildew *(Sclerospora graminicola)* infection 24 June. Symptoms disappeared and reappeared several times as climatic conditions changed but the plants were free of downy mildew at the end of the season. Growth of infector material was reasonably satisfactory but with gaps. Plants that died did so because of inadequate rainfall, sand blasting and burying, and grasshoppers. There was no evidence of fungal problems at the seedling stage.

The same pattern was reflected elsewhere in Niger. Crops generally were thin; downy mildew development was late and damage slight.

Smut. Smut at the Sadore" station was moderate as elsewhere in Niger, but the disease did not reach damaging levels.

We experimented with methods to inoculate with smut, especially in the 'sick plot,' and tried eight methods of establishing a satisfactory screening technique for smut. The one chosen for 1983 is to direct a jet of spore suspension (24-hr old) inside the boot leaf and then cover with a selfing bag. Bagging the developing heads extremely early to exclude external inoculum did not prevent infection.

Ergot. Levels of ergot in the Niamey area were extremely low in 1981; this likely is the general rule under dry conditions.

Striga

We are planning research on *Striga (S. hermonthica)* which affects millet as part of the breeding program. Two areas of the Sadore site (about 1

Attempts to collect* Striga *material from farms in the region around Sadore, Niger, were frustrated by goats.

ha each) that bore a crop of volunteer millet, primarily shibras, were selected for their high *Striga* infestation in 1982. *Striga* inflorescence was collected from the Sadore site to increase *Striga* infestation. Attempts to collect similar *Striga* material from neighboring farms were frustrated by goats.

Moderately severe attacks of a crown rot, probably caused by a species of *Fusarium,* and a gall-forming insect *Smicronyx* sp.) were seen on the *Striga* at Sadore.

Cowpea

In addition to the more prevalent diseases of cowpea, plantings at Sadore were attacked by *Macrophomina phaseolina,* which apparently is widespread and damaging in Niger. It attacked and almost completely destroyed late plantings on infertile soil.

Pearl Millet Agronomy

An agronomist joined our Sahelian Center staff in April 1981, and we initiated work on cultivar adaptability and basic crop agronomy, with emphasis on variety adaptation, cultivar x density interactions, intercropping, and crop establishment. A range of genotypes were planted in six international, regional and local variety trials. Four genotypes (ICH 412, MBH 110,1TV 8113, ITV 8003) yielded as well as, if not better than, a local improved variety, CIVT. With rains ending early (total rainfall 395 mm), higher yields were associated with earliness. Thin-stemmed, high-tillering genotypes were most susceptible to lodging and drought stress.

Preliminary plant density studies in 1981, using four genotypes (MBH 110, Ex Bornu, ICMS 7703, 3/4 HK) showed large interactions between varieties and plant densities for both morphological and yield characteristics. Early genotypes (MBH 110, ICMS 7703) this dry year maintained yields at higher densities than normally used in Niger. Decreasing with increased plant density were single-grain weight, grains per inflorescence, inflorescence length, inflorescence number per pocket, and plant height. In contrast, lodging and inflorescence number per unit area increased with plant density. Useful insights

Preliminary studies indicate that early-maturing varieties of millet may need to be planted denser, particularly in dry years, than is normally practical. Normal density is shown in this field in Niger.

were gained from the plant-density tests; follow-up trials will include both improved local and farmers' varieties, as well as thinning and fertility regimes.

Plant stands were poor on Niger farmers' fields and research plots in 1981/82. Replanting two or three times was normal. Then on average 16% of the pockets were missing in a sample of nine farmers' fields between Niamey and Maradi, and only 55% (average) of the pockets produced productive tillers in the widely spaced plantings (Table 10). Reasons for poor stands are not clear but may be early moisture stress, high soil temperatures, poor seeding techniques, sand blasting, and low germination seed.

The first planting of 1982 experimental fields 3 June gave an average 52% stand with traditional hand planting, 30 seeds per pocket. In early plantings, the local cultivar appeared more vigorous than the improved varieties. In the first planting of the combined agronomy trial, local stands averaged 68%; CIVT varieties, 41%. Poor stands appear to result from early drought and soil-temperature stresses. Soil temperatures 2 mm below the surface rose quickly in June to 45 or 50°C after a rain, and 5 cm below the surface, to above 40°C, so replanting was necessary 30 June and 3 July (Fig.3). Then stand survival was better. Stands of the replanted combined agronomy trial, which contained only local material, averaged 91%, when moisture was more plentiful and temperatures were lower after sowing. After the 30 June sowing, temperatures 5 cm below the surface ranged from 30 to 45°C and rose to between 45 and 50°C late in July.

The exotic materials in the breeding trials produced poor stands because they are not adapted to high soil temperatures, drought stress, or sand blasting and burial.

Table 10. Millet stands between Niamey and Maradi, Niger, 1981/82 survey.

	Millet hills (%)			
Farm field	Productive	Non-productive	Shibras	Missing
1	74	3	14	9
2	66	4	24	6
3	58	23	6	13
4	56	9	20	15
5	52	27	9	11
6	51	20	22	8
7	51	14	4	31
8	46	9	14	30
9	37	24	13	26
Mean	55	15	14	16

Productive = producing inflorescences.
Nonproductive = producing no inflorescences due to disease or insect damage.
Shibras = weedy unproductive *Pennisetum.*
Missing = no plants established in hill.

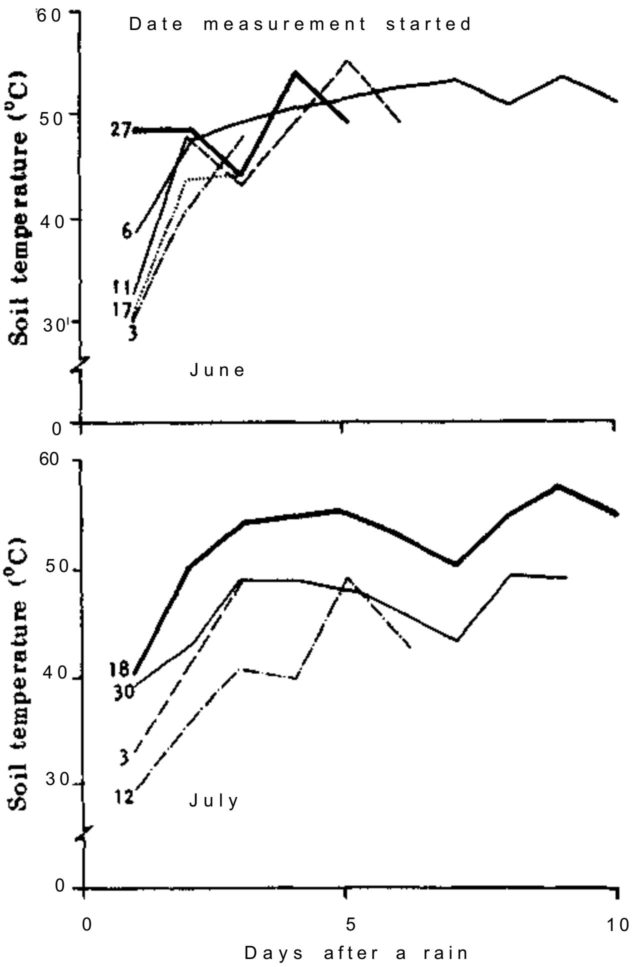


Figure 3. Soil temperatures 2 mm deep in June and July 1982, recorded from one day after a rain, ICRISAT Sahelian Center, Niger.

We started a project to determine cultivar differences in seedling emergence and establishment, and to develop selection techniques that permit us to evaluate differences in stand establishment. Sequential plantings of 30 genotypes after a rain differentiated their abilities to emerge and establish. With refinement, sequential plantings may be a useful selection technique. Varietal differences in emergence and establishment largely reflected original seed viability, except that the local improved varieties, CIVT and HK.P, performed better than their germination percentages indicated, while ICH 226 and MBH 110 performed markedly poorer. The last two, along with WC-C75, ICMS 7703, and ICMS 7909, had higher mortalities of emerged seedlings than the other genotypes. High soil temperatures, exceeding 45°C at times, a common early season phenomenon, associated with drought stress, probably killed the seedlings.

Early drought and high soil temperatures make it difficult to get uniform stands of millet in the Sahelian area, so high-germination seed and proper seeding techniques are needed, as are drought- and heat-resistant cultivars. Replanting was necessary in this field.

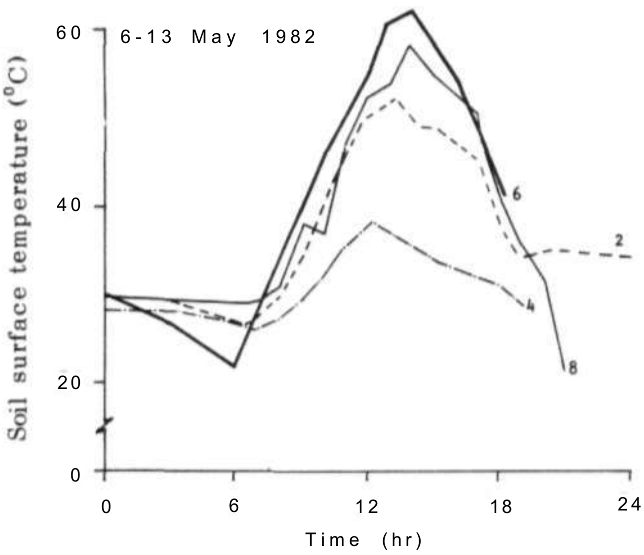


Figure 4. Soil surface temperature at 2, 4, 6, and 8 days after planting for a crop establishment trial with 20 mm irrigation at AGRHYMET Center, Niger.

To test screening for temperature and drought stress, during the April-May prerainy season, we planted a genotype screening trial in 1982 in association with members of the Meteorology Department, Reading University (England), who monitored the environment. Climatic conditions were ideal for temperature stress screening, as soil surface temperatures exceeded 50°C after planting (Fig.4). Significantly more ITV 8201, ITV 8205, and Souna Mali than local cultivars (CIVT, HKP, P3 Kolo, Ankoutess, and 3/4 HK) emerged and survived 15 days after sowing.

With better control of moisture and soil conditions, the prerainy season appears ideal for screening genotypes in a high-temperature environment.

Intercropping. Because millet is grown as an intercrop in the southern Sahelian region, it is important to evaluate two crops together. Most millet in this region is intercropped with cowpeas. We started a project in 1982 to elucidate advantages or disadvantages of intercropping millet and cowpeas, hoping to determine optimum combinations of the two crops in the region and to understand what factors contributed to success.

Increasing cowpeas in the mixture decreased millet grain yields. The local cowpea cultivar was more competitive with millet than the improved grain cultivar TN88-63 (Table 11). The local millet cultivar yielded more grain than CIVT, both yielded more with a plant density of 10 000/ha than with 4400/ha).

Cowpea hay yields were generally the reverse of the millet grain yields for the various treatments. Higher proportions of cowpea in the intercrop gave higher hay yields, and the local cultivar produced more hay than did TN88-63. The local cultivar was more competitive with cowpea than was CIVT. Millet density did not affect cowpea hay yields. No cowpea grain was produced in 1982 because of drought and insect attacks.

Economic returns increased with increasing proportions of cowpea in the intercrop, particularly with the local cowpea cultivar and millet cultivar, CIVT.

For all treatments, land equivalent ratios indicated definite advantages to intercropping with cowpea. To obtain more cowpea hay, CIVT variety should be used in high cowpea-to-millet proportions. To obtain more millet grain, the local cultivar should be used with low cowpea proportions.

Sorghum and Pearl Millet Entomology

Our entomologist in Niger worked also in Upper Volta.

Insect pests in Niger. Results from pest surveys in Niger are preliminary because surveys were less frequent in Niger in 1981 than in Upper Volta in 1979/80 and fewer farms were sampled. The highest *Raghuva* infestation (80%) was recorded in a field in Dogon Doutchi. Highest stem borer infestation (100%) was at Tamaske (Tahoua district). *Raghuva* infestation in 1981

Table 11. Yield and economic return of millet/cowpea intercropping study, Niger, 1982.

Treatment	Cowpea hay (kg/ha)	Millet yield (kg/ha)	Total value	LER Cowpea	LER Millet	Total LER
Millet density						
1 x 1 m^2	540	470	72.3	0.58	0.80	1.38
1.5 x 1.5 m^2	560	340	63.4	0.58	0.57	1.15
SE	±58	±5	±3.9	±0.03	±0.07	±0.09
Cowpea variety						
TN 88-63	360	460	60.2	0.43	0.78	1.21
Local	740	340	75.5	0.73	0.59	1.32
SE	±21	±31	±3.5	±0.06	±0.11	±0.15
Millet variety						
CIVT	600	390	69.9	0.64	0.72	1.36
Local	500	420	65.8	0.52	0.65	1.17
SE	±29	±32	±3.8	±0.08	±0.03	±0.10
Cowpea: millet						
1:3	200	480	51.3	0.22	0.81	1.03
1:2	410	470	63.9	0.43	0.79	\2\
1:1	450	370	58.9	0.50	0.64	1.13
2:1	820	390	84.3	0.85	0.66	1.51
3:1	860	310	80.8'	0.92	0.52	1.44
SE	± 68	±43	±5.7	±0.08	±0.07	±0.11

appeared to be highest in the central region between Dosso and Madaoua.

Pest population dynamics. Adult emergence of *Raghuva albipunctella* correlated highly with the first major rains. Infestation was more closely related to the date that heads emerged than to flowering date.

As in preceding years, we recorded three larval peaks of *Acigona ignefusalis* at Kamboinse in 1981, confirming three generations a season. The third generation, usually the highest, caused major crop infestation in late August and in September. It undergoes diapause during the 6- to 8-month dry period. Larval survival is high during the dry period, especially in millet stalks, preserved as piles, under shade, or as animal bedding.

A. ignefusalis, the predominant stem borer of millet at Kamboinse, is replaced by *Sesamia calamistis and Eldana saccharina* during the dry season. Infestations of sorghum by *Acigona* become predominant in October and November.

Borer preferences for varieties. Varieties Nigerian composite, Ex-Bornu, and Souna III were the most susceptible to borers. Initially the borers preferred Nigerian composite, not the Kamboinse local. By initial varietal preferences the varieties ranked Nigerian composite > Souna III and Ex Bornu > CIVT II > Kamboinse local.

Spittle bug. Spittle bug *(Poophilus cos talis)* infestations increased in Niger as the crop season advanced, and there is evidence that *Locris rubra* did not contribute to this infestation (Table 12).

The chlorotic symptom arising from *P. costalis* infestation did not develop in plants attacked by fewer than six larvae. Infestations were highest in September.

Larvae developed to adults in 23 days. Average adult longevity in captivity was 3.5 days. Larval mortality was higher in the first two than in later nymphal stages.

Research Results

No pest surveys were conducted in Niger during 1982 cropping season, and adult populations of *Raghuva* and *Acigona* were not surveyed.

Results from year-round monthly plantings of millet at Kamboinse, Upper Volta, confirm for the 3rd year that *A. ignefusalis* is the predominant stem borer in millet. Infestation of irrigated millet during the dry season is low and *A. ignefusalis* is replaced primarily by *Sesamia calamistis.*

Larvae from weekly stem-splitting observations showed two distinct *Acigona* generations at Kamboinse in 1982 with the first generation much smaller than in previous years.

Stem borers usually attack sorghum more than millet.

Date-of-planting trial, Kamboinse. Borer damage on young millet, recorded as deadheart tillers, was low with no difference among varieties or planting dates, which is contrary to the 1980 and 1981 results. Detailed analyses of percentages of infested stems, bored internodes, and larvae per stem showed the same trend as in 1981. The local variety was more tolerant than Ex Bornu or Nigerian composite. Initial borer attack was higher in the late crop. The low stem borer damage on the first crop was related to low first-generation larval populations in July.

Table 12. ***Poophilus costalis*** **and** ***Locris rubra*** **infestations on farmers' fields in Niger, 1981.**

Month	Fields sampled (no.)	Adult plants infested (%)	Adult *P.costalis* (no./500plants)	Adult *L.rubra* (no./500plants)
July	16	5	5	> 1
August	24	17	20	> 1
September	25	27	48	> 1

Internode damage and grain yield relations, Kamboinse. Although more than 20% of the stalks examined were not infested by *A. ignefusalis,* 57% had from 1 to 4 internodes destroyed, with no major differences among varieties. Even though differences among numbers of internodes bored per stem were significant, grain yields increased with increased internode damage for all three varieties.

Date-of-planting trial, Sadore. In general the earlier crop suffered less stem borer damage but higher *Raghuva* infestation than the later crop. Differences among entries were not significant at either date.

Sorghum midge. We saw no adult populations of the sorghum midge *(Contarinia sorghicola)* in August at either Kamboinse or Farako-Ba, which confirms this pest's shift in population reported in 1981. Midge populations peaked in late September/early October during the flowering stage of most varieties. IS-15332, PM-9020, and PM-9033 seemed to be most tolerant or resistant.

Soil Chemistry and Fertility

The research program on the sources and management of nitrogen and phosphorus in the soils of the African SAT south of the Sahara was jointly initiated in 1982 by the International Fertilizer Development Center (IFDC) and ICRISAT. The main objective of this research program is to identify the best sources of phosphorus and nitrogen and to determine the most economic methods of applying nitrogen to increase crop production in farmers' fields.

Physical and chemical characterization of soils at the Sadore research station, where the experiment was carried out, showed that they are Oxic Paleustalfs. These soils are sandy (92% sand), acid (pH in water 4.6), and low in available phosphorus (Bray-1 P = 2.4 ppm) and exchangeable bases (60% base saturation).

The isotherm curves of phosphorus absorption were established according to the Fox and Kamprath method. Phosphorus absorption is low in the surface layers but increases with depth. Thus, the quantity of phosphorus required to maintain a standard concentration of 0.2 ppm P in an equilibrium soil solution is 10 ppm P for the soil surface sample (0-15 cm) and 86 ppm P for the subsoil sample (120-150 cm).

Preliminary results obtained during the year show that fertilizer is one of the most important factors for increasing crop production; that the fertility level is low was highlighted by a nonfertilized plot of millet yielding only 17% of the maximum. Phosphorus is the most important limiting factor to crop production; phosphorus alone brings millet yield to 88% maximum.

In the trial on sources of phosphorus, the best two sources were triple superphosphate and partially (50%) acidulated rock phosphate. Partially (50%) acidulated phosphate rock is almost as efficient as triple superphosphate. Since there is no significant difference between the two, sulphur had no significant effect on millet grain yields.

The experiment on sources and application methods of nitrogen showed that supergranulated urea in split applications and urea in split bands are the best.

Split applications of nitrogen are better than a single application with all fertilizer applied as a basal dressing at seeding. For basal application, calcium ammonium nitrate is superior to urea.

Phosphorus absorption isotherms show that maintaining 0.07 ppm P in an equilibrium soil solution at planting produces 95% of the maximum yield.

In the trial on plant density-nitrogen interaction, a population of 20 000 hills/ha, instead of 10000, used nitrogen more efficiently and increased grain yield about 30%.

Economics

Our economist in Niger also worked in Upper Volta in 1981.

Nakamtenga and Nabitenga villages in Upper Volta

Costs and benefits of traditional production. Our results conformed to the general pattern of West African semi-arid tropics farming: There is little activity except weeding until the first rains, usually in late May or early June at Ouagadougou's latitude. Intense planting (and replanting) of the principal cereals (millet, white sorghum, red sorghum) follow the first rains. Then, after a slack period, comes another time of intense weeding, which is nearly two-thirds of total labor time. Little money is spent on inputs (fertilizers, especially) and yields are nearly always less than 500 kg/ha. Labor going on farms generally returns less (by cost of food produced) than the same labor would return in wages.

Granaries in West Africa often are two-story, mud-brick structures like this one with bundles of millet ready for storage. During July and August, before harvest in 1982, 86% of the cereals consumed in Oure, Upper Volla, a Sahelian village of 775 people, was from stored millets.

Cropping patterns. The cropping pattern is undiversified with millet the main crop, covering more than two-thirds of the cropped area in both hand and animal traction (ATR) cultivation. Sorghums are next in importance, ahead of the minor crops, groundnuts (including *Bambara* groundnut) and maize. (We have estimated 0.26 to 0.31 ha of crop area per family member.)

Sites for Western Niger Village Studies

Principal site selection. To compare animal traction (ATR) and hand-tool techniques we needed to find villages where both were used. It was also important that edaphic variability permit us to compare edaphic effects on farmer trials. Additionally, well established farmer-herder relations were needed so exchanges between those groups could be studied. Finally, it was important to identify villages with active commerce, especially in grain and stock, so we could study commercial effects on production and on adoption of technology.

Site selection in the Dallol Bosso region. The Dallol Bosso is a fossil riverbed running south from Filingue to the border of Benin with high population density, high cropping intensity, and diversity of crops—all unusual in western Niger. Soils of the western border of the Dallol are of the Tantchia series, similar to those at the Sahelian Center.

We chose this border, a sandy plateau, because it also provides an opportunity to study millet-based farming systems with few improved techniques in a relatively high population area. The area is crossed by the main national east-west road at Birnin Gaoure (13°05' N); annual rainfall averages 605 mm.

Villages chosen in the Dallol Bosso region. Our interviews established that the subregion is homogeneous in agricultural techniques, cropping patterns, rainfall regimes, and social institutions.

Too little animal traction was found for it to be studied here. The villages chosen, Fabirgui and Gobery, had herders or a nearby camp of herders, and are 15 to 25 km from the main east-west road of the country, at the edge of the Dallol about 20 km south of the paved road, not isolated from commerce. The villages are close enough together so rainfall should not vary significantly between them, over time or during a season.

Site selection in Zarmaganda. Zarmaganda is the subregion north of Niamey between the Niger river and the Zgaret fossil basin. It is humid with rainfall from 200 to 550 mm per year. Soils are fairly uniformly sandy with irregular topography. Much of the zone is traversed by dry tributaries of the Niger river. Population density varies widely—from 1 to 30 persons/sq km in rural areas, but livestock density is high and the zone is crossed by transhumant herds.

The Zarmaganda villages (Sadeize Koira and Samari) are in the most difficult pearl millet, sandy soil areas. Sadeize Koira is roughly 80 km north of Niamey: Samari is about 55 km northeast of Niamey. Most of the cropped land in the two villages is on valley soils, with hill areas used little for cropping.

This subregion is distinguished from the Dallol by lower rainfall, lower population density, greater reliance on early-maturing millets, and poorer access to markets.

Neither Sodeize Koira nor Samari villagers use animal traction, but they vary in slope of soil, soil type, and marginal land for expanded cropped area.

Our principal activity in 1982 was to establish long-term studies in the zone served by the ICRISAT Sahelian Center at Sadore. The low rainfall (400 to 600 mm/year) is highly variable. Production systems are based almost entirely on millet and use traditional hand tools with almost no chemical fertilizers.

Farmers' Tests of Extension Packages

In two of the villages (Gobery and Sodeize Koira) the economics program, collaborating with the agronomy and millet improvement programs, analyzes economic and agronomic effects of millet production packages in Niger, rather than recommending them to participating farmers.

Description of Tests

The test includes four treatments, each in a 500-m^2 block. In the first, farmers were instructed to seed the local millet at the local rate as a control and to thin and weed as usual. In the improved local treatment (T2), farmers were instructed to plant the local millet at 10 000 pockets/ha with 100 kg/ha of simple superphosphate (SSP) and 30 units *of* N/ha as urea. The third (T3) was identical with T2 except that the introduced cultivar CIVT replaced the local millet. The fourth (T4) was identical with T3 except that cowpea variety TN 8863 was added as an intercrop with CIVT.

Test Results

Twenty-eight farmers in Gobery (100 km southeast of Niamey) planted the tests 23 May after 40 mm rain, and 26 farmers in Sadeize Koira (80 km north of Niamey) 3 June after 40 mm rain. Mean emergence 1 week after planting was from 74% (T3) to 82% (T1) in Gobery and from 85% (T2) to 92% (T4) in Sadeize Koira. Rainfall in Sadeize Koira in 1982 was 240 mm; in Gobery, 540 mm. Days from rain to planting significantly affected emergence in both villages: 10% per day-elapsed in Sadeize Koira and 1% in Gobery.

Adding fertilizer increased total labor used in all fields but did not increase weeding labor used. Adding cowpeas (to T3 to create T4) increased total labor used in village fields only, not in bush fields, and not weeding labor in any field. In Sadeize Koira fertilizer use did not significantly affect total labor used at any field; improved intercropping increased total labor used only in fields near compounds.

Treatments containing the introduced cultivar CIVT yielded significantly less ($P < 0.10$) than the fertilized local in Gobery, but at Sadeize Koira, the CIVT cultivar significantly ($P<0.05$) outyielded the fertilized local. The improved local yielded significantly (*P* < 0.01) more at Gobery than at Sadeize Koira.

Production budgets used to test hypotheses about returns to fanners' labor, with official prices of fertilizers and millet, showed that in Gobery, only T2 (the fertilized local) gave returns superior to those from the unfertilized local (T1), then only with fertilizer prices heavily subsidized. The other improved treatments (T3 and T4) were either not significantly better or *not* so good as the local with subsidized fertilizer. In Sadeize Koira differences among treatments in return per hour to fanners' labor at official prices did not differ significantly.

Budgets with market prices of millet and fertilizers showed that Tl gave the highest returns, lowest variation, and financial losses least often in Gobery. In Sadeize Koira, conclusions with economic prices were similar.

Comparisons between Sadeize Koira and Gobery demonstrated that, for a given treatment, returns to labor in Sadeize Koira were always lower and varied more widely and financial losses were more frequent.

The apparent small contribution that density makes to yields or yield variation indicates that density's importance has been overestimated for this area.

Nigeria

Sorghum Breeding

The primary objective is to breed sorghum cultivate for production systems with higher yields and stability across a range of West African environments. Short-season, pest-resistant cultivars adaptable across a range of environments and planting dates could be useful in the drier areas of the north. An assured high-yielding crop is needed for the period when rainfall is most stable in the moderately heavy-rainfall, north Guinean zone and an early-maturing, late-sown crop in the long-season, heavy-rainfall, south Guinean zone. Such cultivars would help in designing and developing stable and productive cropping systems to replace the subsistence mixed/intercropping traditionally practiced.

Adapting Tropical Cultivars

During 1981, potentialities and problems involved in introducing tropical cultivars were assessed. Studies with two commercial hybrids (CSH-5, CSH-6) and two improved varieties (SPV-221, SPV-245) across a range of environments showed possibilities for adaptation as normally sown crops in low-rainfall areas and late-sown, short-season crops where rainfall is high and the growing season long. Despite poor management, low populations, and an abnormal season, yields ranged from 1200 to 3400 kg/ha. Better management with superior cultivars could rapidly increase yields. SPV-245 was identified as a useful introduction, and Kano and Bauchi state governments launched seed multiplication of SPV-245.

Insect and Disease Resistance

Host plant resistance is particularly significant in adapting cultivars to diverse environments.

Seedling deadhearts. Both stem borers and shoot flies cause seedling deadhearts. During normal-season plantings, deadhearts result primarily from stem borers (mainly *Busseola fused),* with shoot flies occasionally attacking late plantings.

Studies during 1981 at Kano and Samaru revealed significant varietal differences related to seedling deadhearts, mainly from stem borers. Increasing applied nitrogen increased deadheart percentages, which were high under low populations at both Kano and Samaru. Both nitrogen x cultivar and population x cultivar studies indicated that borers prefer vigorous plants, but shoot flies prefer weak ones. The interactions indicate scope for selecting vigorous seedlings that resist stem borer attacks.

Forty days after we planted sorghum in 1982, we studied seedling deadhearts (primarily from stem borers) at Samaru, Kadawa, Mokwa, and Yandere. At Samaru we also recorded deadheart percentages in a late-July planting under serious shoot fly attack. All the trials were replicated. The varietal differences resulting from 48 entries were statistically significant ($P < 0.05$).

Entries that showed lowest deadheart percentages were S 36, S 40 and S 2. We have analyzed shootfly resistance from five environments. The stablest varieties were S 40, S 36, S 35, and S 2.

Mature plant resistance to stem borer. During 1981, stem borer tunneling was heavy at Samaru. Because we could not estimate tunneling percentages in all entries, we shook the plants vigorously at harvest time and estimated percentages of plants that did not break. We identified entries with moderate resistance and found SPV-314, SPV-315, and some of their selections promising.

Stem borer damage was less in 1982 than in 1981. Stem borer tunneling seemed not to affect grain yields. Apparently selected entries have reasonable tolerance.

Disease resistance. During 1981 we identified lines highly tolerant to gray leaf spot *(Cercospora sorghi),* anthracnose *(Colletotrichum graminicola),* and sooty stripe *(Ramulispora sorghi).* Leaf disease incidence was lower in 1982 than 1981, but reactions recorded during 1981 were maintained. October 1982 rains caused molds to develop so we scored all entries for mold incidence. Eighteen entries were most promising for mold resistance and agronomic traits.

Durable resistance. By screening breeding material from dry to wet locations under various planting dates, we identified lines resistant to potential pests. We will use them in future studies.

Selecting Tropical Cultivars for Adaptation

We used 1981/82 rainy season and off-season evaluations to select about 50 lines for yield evaluations during 1982—at Kano and Maroua, Cameroon, (dry zones), Samaru (moderately wet North Guinean zone), and Mokwa and Yandev (long-season South Guinean zone). Additionally a West African regional trial was conducted at Samaru.

The performances of the promising lines are summarized in Table 13. The trials clearly separated high-yielding from the low-yielding lines. We also recorded their reactions to insects and diseases and yields under a range of planting dates and locations. The yields reported are at constant populations of 50 000 to 55 000 plants/ha, the optimum for local *fara fara* and available improved varieties. But populations of short, early maturing varieties may go to 150 000/ha.

Lines S 40, S 35, S 19/20, and K 4 were promising under August plantings and a range of planting dates.

Striga-resistant SRN-4841 could provide the basis for improving West African sorghums.

Evaluating Sorghum Collections

We found 60 collections from Africa were not useful, but IS8245, a late line with panicles like broom corn, was not attacked by leaf diseases.

During 1982, a sorghum collection of 203 entries from northern Nigeria was critically evaluated for adequate variability and advantages of hybrid races. The collection provided little variability for leaf spot resistance. Twenty-two collections offered some resistance to stem borers. Grain yields ranged from 13.7 to 172.7 g/plant with a mean of 98.1 g and standard deviation 35.7. Using one standard deviation as the class interval, we divided yield classes into five groups. The frequency distribution for grain yield was near normal.

Lines with an average single plant yield of more than 135 g/plant were the highest yielding. Fourteen lines combined stem borer tolerance with high grain yield.

Sorghum pathology. ICRISAT sorghum pathology research in Nigeria was carried out at Samaru only in 1981. Of 26 entries in field and laboratory studies of sorghum grain mold, four (M 90737, M 62522, M 63935, and M 36190) were most promising.

None of the entries in the Sorghum Downy Mildew Nursery, except the susceptible controls, was infected by downy mildew. Among sorghum downy-mildew differentials tested, FSPR local,

Table 13. Fourteen promising sorghum selections ranked by grain yield, Nigeria, 1982.

Selection/ entry	Pedigree	Initial stand (x 000)	No. of heads at harvest (x 000)	% mean deadhearts	Plant height (cm)	Days to flower	Grain yield (kg/ha)
SRN-4841		53	66		200	64	5470
S40	Eth. 12089	57	51	16	230	77	5090
K4	M 36037	67	61	28	180	70	4780
S34	Sepon 103 (1980 nursery)	57	55	31	180	76	4730
S32	A 6213	57	53	39	170	76	4620
SI7	SPV-314	56	57	27	150	70	4590
S35	M 91019	58	52	26	190	62	4490
S 19/20	SPV-315	60	58	27	150	73	4410
SPV-245		54	49	27	150	76	4300
S38	H 166	59	61		190	69	4160
S37	M 36170	60	55	30	210	81	4110
S10	SPV-301	55	59	29	150	71	4080
S36	M 90411	59	56	22	160	71	4040
S13	SPV-313	57	61	28	140	71	3810

DMS 652, IS 8283, IS 643, and *Sorghum sudanense* were infected.

Many entries in the Sorghum Leaf Disease Nursery resisted major leaf spot diseases. And promising local entries were identified.

Sorghum Entomology

Stem Borers

The predominant stem borer at Samara in 1981 was *Busseola fusca,* which accounted for 90% of the borers, while *Acigona ignefusalis* made up most of the remaining 10%. Infestations reached 100% in some plots with up to four larvae per stalk. Mid-July plantings of two local cultivars, L-1499 and L-187, had more stem borer infestation than late-June plantings. There was no correlation between stem borer infestation and grain yield.

Percentages of plants infested by stem borers in the International Sorghum Stem Borer Nursery varied from 63 to 100, with 28 to 69% of the stalks tunneled. Entry IS-18810, with the least stalk tunneling, also yielded the lowest, while the highest grain yielding entries, IS-10711 and IS-18427, had the highest stem borer damage (87% and 100% of the plants infested, 50% of the stalks tunneled).

Percentages of plants infested in the ICRISAT-Sudan Sorghum Stem Borer Nursery were lower (0-30) and stalk tunneling ranged from 13 to 65% but grain yield was very low, highest in S-95, which had 55% of the stalks tunneled. The ICRISAT-Nigeria Sorghum Stem Borer Nursery had 15 to 65% plant infestations and 11 to 41% of the stalks tunneled. Again, stalks tunneled and grain yields failed to correlate in any nursery. Differences in infestation may be attributed to planting dates. ICRISAT-Nigeria and ICRISAT-Sudan Nurseries were planted in mid-June; the International Nursery, about 10 days later.

Head Bugs

All sorghum plots were sampled weekly for insects in sorghum heads. The most abundant head bugs were mirids (80%), Lygaeidae, Pentatomidae, and Coreidae. In all, 14 species of head bugs were tentatively identified from sorghum heads at Samaru.

Eleven entries of the International Sorghum Head Bug Nursery did not flower; of those that did, IS-16572 and DJ-6514, had the lowest head bug score (averaging less than 1 per plant). Again one of the highest yielding entries, CSH-1, had the highest head bug score, 1.6 per plant. The Preliminary Sorghum Head Bug Nursery provided five entries with scores averaging less than one: PHB-795, PHB-931, PHB-926, PHB-902, and PHB-161.

Shoot Fly

Main stem deadhearts ranged from 38 to 86% (mean 60%) in the International Sorghum Shoot Fly Nursery (ISSFN) and 48% in the Preliminary Sorghum Shoot Fly Nursery (PSSFN). The same two entries in both nurseries, PSF-14103 and PSF-12545, yielded highest despite 50% main stem deadhearts. In the International Nursery, entry PSF-14435 had the fewest deadhearts (38%) but ranked 14th in grain yield; in the Preliminary Nursery it had 43% deadhearts and ranked 17th in grain yield. Entry PSF-13703 in both nurseries had 44% deadhearts (ranked 2nd in ISSFN and 11th in PSSFN), while in grain yield it ranked 7th in the International Nursery and 4th in the Preliminary Nursery.

We related 1982 stem borer populations in Samaru to date of planting to determine the best time to plant sorghum when evaluating stem borer resistance with natural populations. The International Sorghum Shoot Fly Nursery was evaluated for stem borer resistance.

Data from planting various sorghum cultivars on various dates indicate that planting in early July can result in higher *Busseola* infestation but only by the third generation.

Busseola infestations in the Sorghum Breeding Sorghum Stem Borer Nursery ranged from 13 to 92%, mean 44%; while internodes bored ranged from 3 to 29%, mean 11%. Entries S-19, S-4, K-1, S-3, K-2, S-41, S-44, and S-6 had the lowest stem borer ratings. Only K-2 and S-41 had low ratings in both the entomology trial and sorghum yield trials.

Stem borer infestations in the West African Sorghum Yield Trial ranged from 47 to 100%, mean 73%; and internodes bored ranged from 12 to 48%, mean 25%. The Striga-resistant entry had the highest stem borer rating.

Stem borer infestation in the International Sorghum Stem Borer Nursery varied from 37 to 90%, mean 66%; and internodes bored ranged from 9 to 42%, mean 22%.

The material from germplasm collection had stem borer infestations from 80 to 100%, mean 99.6%, and infestation was 100% in 190 of the 195 entries. Internodes bored varied from 12 to 80%, mean 40%.

Sorghum head bugs collected from a medium-maturity sorghum (S-18) reached maximum 5 weeks after the boot stage (130 adults and 750 immatures per sample of 5 heads). They declined sharply the final 2 weeks before harvest.

Main stem deadhearts in the International Sorghum Shoot Fly Nursery in 1982 ranged from 26 to 66%, mean 43%. Entries with less than 30% deadhearts were IS-4663, PB-21318, PB-14103, and IS-5484.

Pearl Millet Breeding

In 1981/82 we focused our work on developing improved millet cultivars with wide adaptability and high, stable grain yield potential.

We conducted three trials at Samaru and Kano in 1981 to compare 22 of the 69 improved selections (a 3rd year) with Nigerian Composite and Ex-Bornu, both improved local varieties. Grain yields ranged from 1140 to 2610 kg/ha at Samaru and from 2680 to 4320 kg/ha at Kano.

Six of the 183 African x African germplasm parent F_1 progenies received from ICRISAT Center, consistently provided useful progeny in crosses.

We yield tested 44 improved genetic selections in three advanced millet yield trials in and outside Nigeria during 1982. Results from outside Nigeria are to provide guidance on the adaptability of program-developed materials in other millet-growing zones in Africa. Through the trials we furnished our materials to other researchers in the region.

A preliminary millet yield trial of 16 entries was conducted at Kano and Samaru.

Our 12 best lines were yield tested at 10 locations in African countries in all four major millet zones. The entries generally showed good adaptation; several performed similar to or better than the local controls in Niger, Upper Volta, Cameroon, Sudan, and Nigeria. The most promising nine entries were: INMB-12, INMB-70, INMB-4, INMB-32, INMB-46, INMB-33, INMB-72, INMB-40, and INMB-20.

Most of the selections matured earlier and were shorter than local controls. AH had fewer stem borer attacks than the local control at Samaru. Their reaction to downy mildew was comparable to that of the controls, but the controls showed more resistance to ergot and smut.

An additional set of 32 advanced improved selections was evaluated at Niamey, Kano, and Samaru with Nigerian Composite and Ex-Bornu controls at Kano and Samaru. The results were encouraging in regard to grain yield, downy mildew resistance, early maturity, and reduced plant height. Eleven were selected for high potential in Nigeria. At Niamey, eight selections showed some potential. The entries generally resisted stem borer attack and downy mildew disease but suffered more from smut and ergot diseases than the local controls at Kano and Samaru.

We evaluated 279 selections ranging from the F_3 to pure-line generations of inbreeding in a downy mildew disease-sick plot. Disease incidence in the nursery was increased by artificial inoculation. A set of 253 single plants of good agronomic type was selected as base females for a crossing block; 268 single plants were selected as male parents in the crossing block.

Pearl Millet Entomology

The millet entomology program started during the 1981 cropping season with observation plots, planted in late June at Samaru, of two local improved cultivars, Nigerian Composite and Ex-Bornu. The millet stem borer, *Acigona ignefusalis,* was the most important insect in that late-planted millet; 100% of Nigerian Composite was infested and about 85% of the heads were blasted. Dissected stalks were completely tunneled with more than 50 larvae per stem.

The 1982 millet entomology program at Samaru consisted of stem borer population studies in relation to date of planting, and evaluating millet cultivars from the millet breeding program for stem borer resistance.

Millet cultivars Nigerian Composite, Ex-Bornu, and Farmer Local, had fewer stem borer attacks (50-80% infestation and 8-10% internodes bored at harvest) when planted in mid-June rather than in mid-July (100% infestation and 60% internodes bored). Nigerian Composite was more susceptible to stem borer attack than the other two cultivars. Late planting decreased grain weight from 20% in Nigerian Composite to 50% in Farmer Local, but 1000-seed weight decreased only in Nigerian Composite and Ex-Bornu and increased in Farmer Local. The data indicated early July as the best time to plant millet cultivars for stem borer evaluation by natural populations.

Acigona infestation in the Millet Breeding and Stem Borer Nursery varied from 93 to 100% (mean 99%), while internodes bored varied from 47 to 75% (mean 63%). Three entries, 1NMB-22, INMB-46, and INMB-37, had the lowest infestations and grain weight of each was near the average of 694 g for a 5-meter row plot. INMB-12 had the highest grain weight (1115 g) but it ranked 27th of 31 entries for stem borers. The same material in the millet yield trials had lower infestations (43 to 85%, mean 66%) and fewer internodes bored (7 to 31%, mean 23%). Entries KMDC and INMB-53 had low stem borer ratings but only INMB-46, INMB-31, and KMDC had low ratings in both the entomology trial and millet yield trials.

Pearl Millet Pathology

Many millet genetic materials were screened in the local, regional, and international nurseries for the three major diseases—downy mildew, smut, and ergot—at Samaru and Kano locations during 1981.

Among the 150 entries evaluated in the Pre-

International Pearl Millet Downy Mildew Nursery at Samara (Pre-IPMDMN), 14 were highly resistant to downy mildew up to the dough stage (about 60 days). Of 45 entries in the International Pearl Millet Downy Mildew Nursery (IMPDMN), 10 showed good resistance up to dough stage at both locations with minor variations by D-4 and ICH 226.

In the International Pearl Millet Smut Nursery (IPMSN), four entries showed satisfactory resistance (severity < 10%).

None of the 30 test entries in the International Pearl Millet Ergot Nursery (IPMEN) resisted ergot; ICMPE 34-1-10 had the lowest infection (12.5%). Additionally, most of the entries (23 of 30) were heavily infected with downy mildew.

Six of 33 test entries in the Elite Variety Trial (EVT) were highly resistant to downy mildew (infections from 2.2 to 9.4%). None, however, was highly resistant to ergot. By their overall performances, entries MC-P 8001, IVC-P 8001, IVC-P 8002, and SSC-A 80 appeared promising.

Most of the 23 test entries in the Pearl Millet Advanced Synthetic Trial (PMAST) were moderately resistant to downy mildew, and these five had low incidences of ergot disease under natural field conditions: ICMS 8034 (3%), WC-C75 (5%) and ICMS 8025, ICMS 7916, and ICMS 8019 (each 8%). Smut infection was low in 7 entries: WC-C75 (1%), ICMS 8034 (3%), ICH-165 (5%), ICMS 7916 (8%), and ICMS 8024, ICMS 8010, and ICMS 8014 (each 10%).
On the other hand, only three entries, ICMS 8139, ICH 165, and ICMS 8138, showed high resistance to downy mildew in the Pearl Millet Initial Synthetic Trial (PMIST). Some of the entries (ICMS 8102, 8148, 8147, 8150, and 8152) showed only 1 to 5% ergot infection.

Most of the 16 entries in the Disease Observation Nursery for Improvement of Advanced Hybrids (DONIAH) resisted downy mildew but none resisted ergot or smut.

In the VCF_1 progeny nursery, entries 1, 4, 6, 12, and 13 had acceptable disease resistance. Only two of the F_3 crosses, (700651 x[J 260-1 x 700557-1-4-10-5]-1 and EB 237-3-1 xP 7x[P 7x SC-I(S_4)27-2-1]1) were promising.

Three of the 30 local collections made in 1977 (IMPS 8002, 8011, and 8036) continued to be free from downy mildew and the rest showed high resistance; IMPS 8009 also was highly resistant to ergot.

Most progenies from the IMPS lines x Ex-Bornu crosses remained highly resistant to downy mildew but not to ergot.

Eleven of 15 entries in the West Africa Disease Resistant Elite Varietal Trial (WADREVT) were highly resistant (infection less than 5%) to downy mildew. And incidence in the rest was less than 10%. All were moderately resistant to ergot and smut diseases.

Most of the 25 test entries in the Experimental Varietal Trial (EVT) were highly resistant to downy mildew.

Pearl Millet Agronomy

Four pearl millet projects during the 1981 season were: (1) collecting germplasm from local markets and farmers in parts of northern Nigeria to increase variability in local millet germplasm, (2) evaluating the collected germplasm samples for local adaptive characteristics and selecting some for improvement, (3) determining relative responses of local and newly developed cultivars to nitrogen levels, and (4) studying intrarow plant spacing of local and improved cultivars.

Ninety germplasm samples were collected and given to the national program and to ICRISAT Center. In the agronomic evaluation of samples, many individual plants were selected for improvement.

In none of six agronomic characteristics measured (days to flower, plant height, ear length, ear weight/ha, ear number/ha, downy mildew incidence) was the cultivar x N-level interaction significant. Differences in responses between local and newly developed cultivars to 20, 40, 80 kg of N/ha were not significant. Except for downy mildew disease incidence, intrarow plant spacing did not seem important in selecting for the six agronomic plant characteristics. As in the millet variety x N-level fertilizer study, grain yield was not measured because of severe bird damage.

Senegal

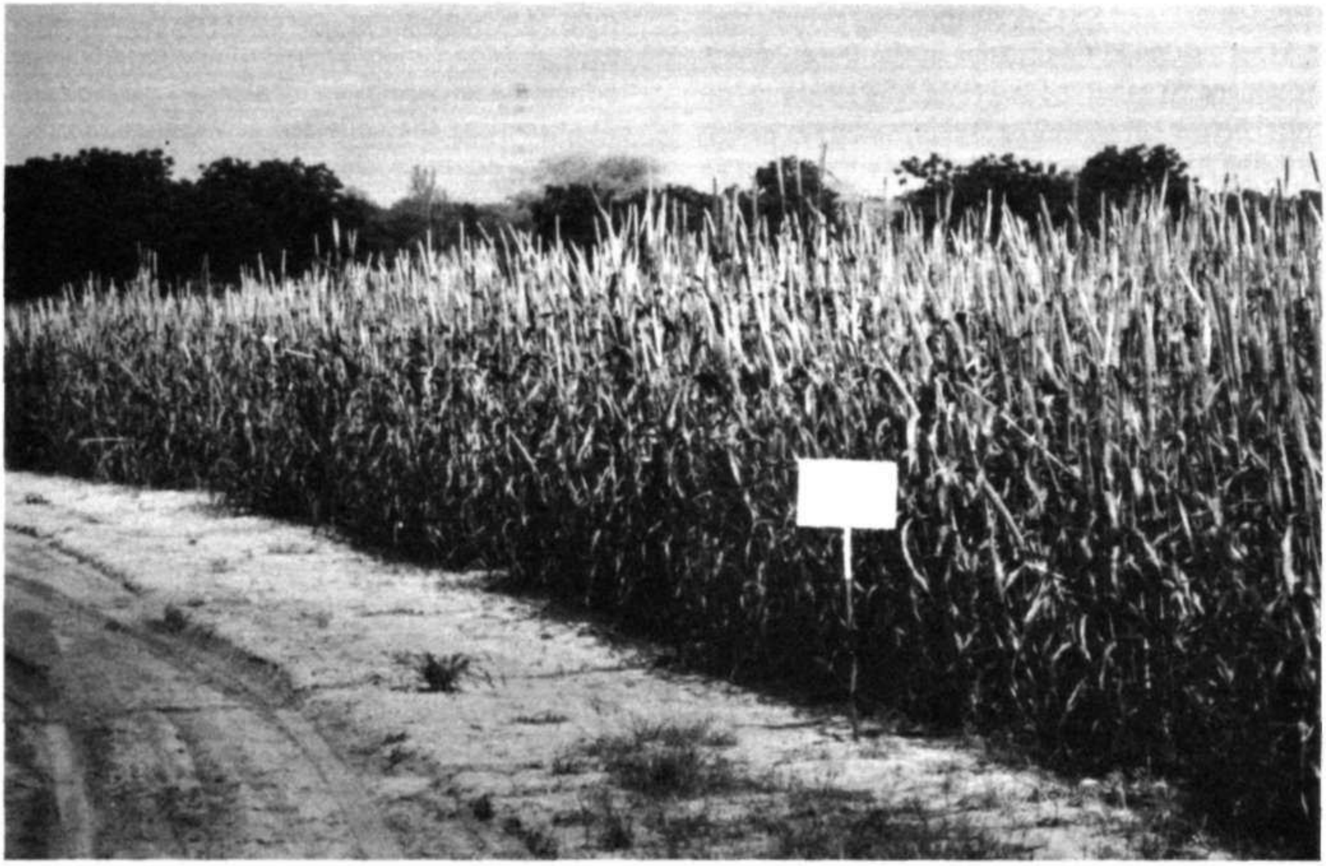
Pearl Millet Breeding

The material generated by our breeding program, along with introductions, was used to develop synthetics 1BV 8001 and IBV 8004 and a few inbreds, such as IB1 8108, and to use in further crossing to generate new breeding material. Recently we have been using more Senegalese landrace material in crosses with non-Senegalese parents to generate new variability, which will provide progeny for new synthetics and other purposes; 260 of 1719 such crosses grown in 1982 were selected for generation advance.

During 1982, synthetic IBV 8001 gave significantly higher grain yields in advanced trials than either the standard (Souna III), or farmers' local. Over 3 years both IBV 8001 and IBV 8004 averaged 22% more grain yield than Souna III, and had better downy mildew resistance, but both have shorter heads and still require further improvement for uniformity. Both have been recommended for prerelease demonstrations and are being evaluated by independent extension agencies.

Souna III and IBV 8004 were in the S1 progeny selection program for the first time in 1982. The selected progenies are being recombined during the off-season. Synthetic IBV 8001 is being improved, through a gridded mass selection, mainly for uniformity and head characteristics.

Breeding for resistance to diseases and pests was initiated in collaboration with Institut Sene-



ICRISAT-developed synthetic millet IBV 8001 (above), has consistently outyielded Souna III and farmers' local for 3 years in Senegal. It is being recommended for prerelease demonstrations and is being evaluated by independent extension agencies.

galais de Recherche Agricole (1SRA) millet pathologist and a cooperating entomologist. We attempted to develop an artificial disease nursery for screening against downy mildew at Bambey but succeeded only partially, for lack of perforated-pipe irrigation.

A small project on development of hybrids and male-sterile lines was begun.

A multidisciplinary project involving millet physiologists from ICRISAT Sahelian Center, and an ISRA soil chemist was started in 1982 to determine fertilizer dose, spacing, and plant population for newly developed synthetics. Preliminary results indicated that the optimum plant population for different varieties ranged from 18 000 (Souna HI) to 40 000 (H7-66) plants/ha.

In another experiment on fertilizer dose and spacing, high fertility (61-31-31 kg/ha) and 90 x 30 cm spacing (1 plant/hill) produced significantly more grain than low fertility (31-21-21 kg/ha) and 90 x 90 cm spacing (3 plants/hill). Though the results are preliminary, they indicate that such experiments are useful.

IBV 8004 was contributed to two regional trials; IBV 8001, to one.

In coming years, our major emphasis will be exploiting crosses made during 1981 and testing new synthetics in farmers' fields.

Sudan

Sorghum Breeding

Sorghum research during the 1981 and 1982 crop seasons was carried out at five locations—Wad Medani (Gezira Province), Gadambalia (Kassalla Province), Agadi (Blue Nile Province), E1 Obeid (northern Kordofan Province), and Kadugli (southern Kordofan Province). Those stations represent the environments of the major sorghum-growing zones in the northern two-thirds of the country.

Considerable progress has been made in sorghum improvement research in the Sudan during the last two seasons.

Breeding nurseries. We have been intercrossing exotic and local sorghum germplasm since the ICRISAT-Sudan Cooperative Program started in 1977. Our objective is to diversify local germplasm and improve local varieties for earliness, grain quality, and high yield potential. Multilocational evaluating and selecting early crosses during 1979-1982 has begun to yield good results. At the end of the 1982 crop seasons, C2 diverse pure lines combining earliness, good grain quality, and high yield potential were selected. About 80% of them were better in all aspects than the best local variety, Dabar 1/1.

Local sorghums—collection, evaluation, and maintenance. We collected 373 local sorghum types during the 1979, 1980, and 1981 crop seasons, and grew them all for characterization, evaluation, and maintenance. The collections came from previously collected areas, through expeditions or cooperation with INTSORMIL, and USAID/Harvard colleagues in other development projects in the Sudan. Using the list of plant characteristics in the Sorghum Descriptors, we characterized each cultivar during 1982 for 22 morphological characters. We have also identified outstanding local sorghums to use in crosses.

Variety trials. To identify elite varieties with good adaptation, we routinely conduct multilocational variety trials each season, both locally organized and introduced.

In the locally organized yield trials, called Elite Sorghum Varieties Yield Trial (ESVYT) and Selected Sorghum Varieties Preliminary Yield Trial (SSVPYT), some elite entries performed well across locations in both 1981 and 1982. Entries M90950, M90393, P-967083, SPV-138, and M-62641 were particularly promising under irrigated or rainfed conditions.

In ICRISAT's Sorghum Variety Adaptation Trial (ISVAT) during 1981 and 1982, six entries (M-36136, M-39335, SPV-138, M-36178, S-6250, and A6102) performed well in 1981 both at Gadambalia and Wad Medani. In the 1982 trial, highest yielding entries were M-60252, M-60262, and SPV-245.

In the 1962 African Regional Sorghum Varieties Yield Trial, the highest yielding entries were from Sudan. Su.Cr.35-5 and Dabar 1/1 ranked first and second, and M-62641 from Wad Medani ranked third.

Hybrid program. In the last four seasons (1979-82) we have synthesized and evaluated more than 3000 new experimental hybrids under both irrigated and rainfed conditions. The tests under irrigated and rainfed conditions in 14 locations have led to our identifying three elite hybrids with a combined mean average yield of 50% more than open pollinated local varieties. Experimental seed production of these elite hybrids, each on a 0.42 ha area, during 1982, gave 4570 kg of EEH-1 and 4170 kg of EEH-3 per hectare (Table 14).

The results of 4 years' yield trial data and experimental seed production testing (Tables 14 and 15) were presented by the Gezira Research Station to the Sudan Plant Propagation and Variety Release Committee; the Committee officially released experimental hybrid EEH-3 as the first commercial sorghum hybrid in the Sudan and gave it the Arabic name "Hageen-Durra-1" (Sorghum Hybrid 1).

Table 14. Seed yield (kg/ha) of experimental seed production testing of three promising elite experimental sorghum hybrids and their female parent, GRS farm, Sudan, 1982.

Seed field	Pedigree	Seed yield (kg/ha)[1]
EEH-1	TX 623A x Su.Cr. 54: 18/17	4570
EEH-2	TX 623A x Su.Cr. 36: 80/70	3630
EEH-3	TX 623A x Karper 1497	4170
A x B	TX 613A x TX 623B	5460

1. Planting arrangement was 2 rows of pollen parent and 4 rows of seed parent. The recorded yield is from 0.28 ha.

Breeding for drought resistance. Our research on breeding for drought resistance was limited to screening sources considered drought resistant under droughty field conditions and using drought-tolerant local sorghums in crosses. Germplasm materials for screening have been received from ICRISAT Center, Purdue University, Texas A&M University, University of Nebraska, and the Ethiopian Sorghum Improvement Project. Two locations, Gadambalia and E1 Obeid, with mean annual rainfall of approximately 550 mm and 350 mm, respectively, are the testing sites for drought work.

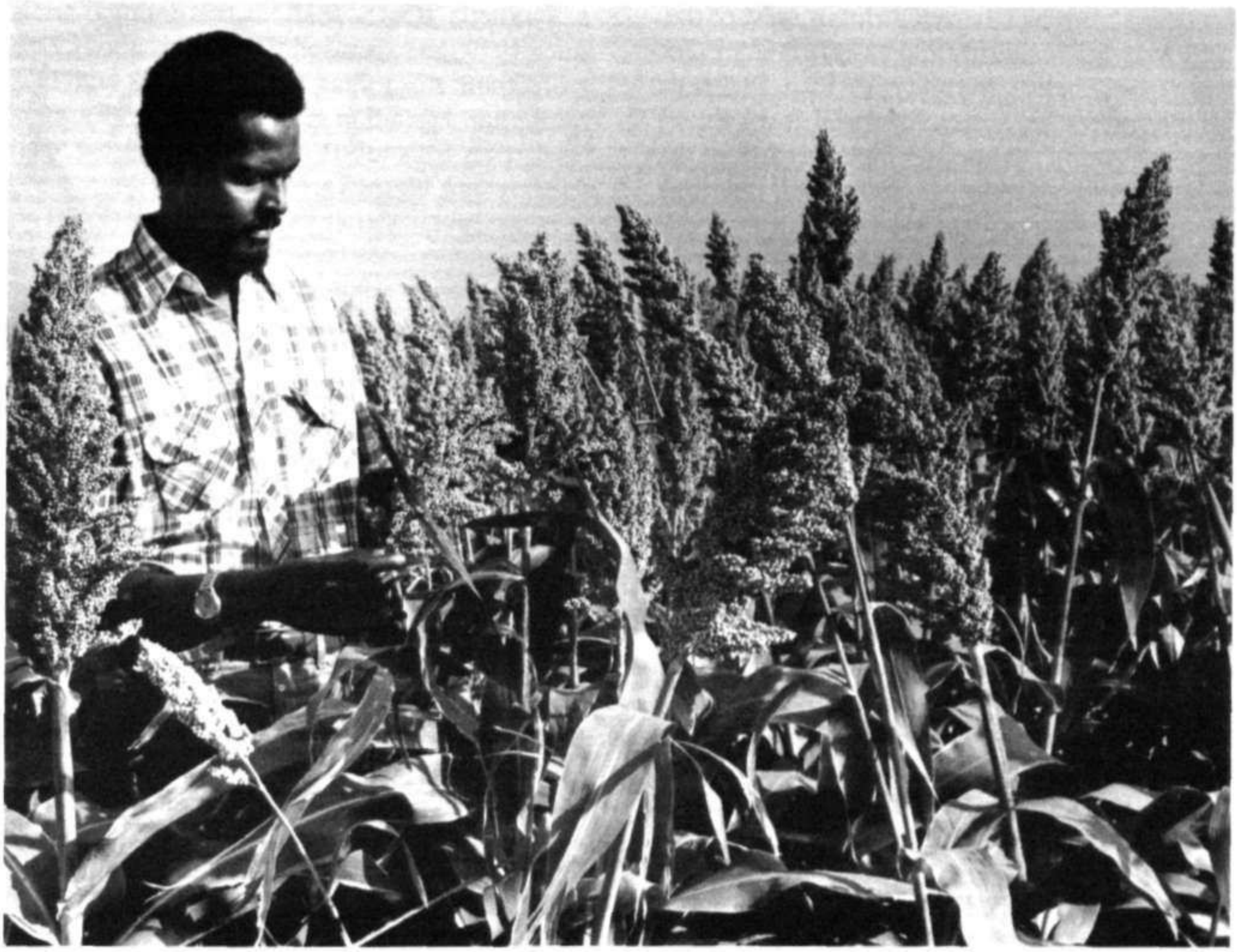
Progress made is encouraging; drought-tolerant selections P-898912, P-967083, Karper 886, IS 2321, DJ 1195, and D 71245 performed well in both 1981 and 1982, as in previous years.

Breeding for *Striga* resistance. A valuable discovery we made during the 1981 crop season resulted purely from serendipity. A set of elite varieties in the yield trial at Kadugli was inadvertantly planted in a *Striga-infested* field. Yields from the set showed good tolerance to *Striga* with neighboring plots showing high susceptibility.

In 1982, those Striga-resistant varieties and other selections identified from previous years' screening at Wad Medani were tested with a

Table 15. Summary of yields (kg/ha) of three promising experimental sorghum hybrids over four crop seasons (1979-1982) under irrigated and rainfed situations (21 yield trials), Sudan.

	Irrigated		Rainfed		Total	
Pedigree	Yield	% Local	Yield	% Local	kg/ha	% Local
T x 623A x Su.Cr.54: 18/17	5820	178	2410	123	4110	157
T x 623A x Su.Cr.36: 80/70	4780	146	2210	113	3490	134
T x 623A x Karper 1597	5190	158	2970	152	4080	156
Mean	5260	161	2530	129	3890	149



Sorghum hybrid in Sudan: its combined average yield—50% more than open-pollinated local varieties over 4 years at 14 locations—led to EEH-3 (above) being released as the first commercial hybrid in Sudan, under the Arabic name "Hageen-Durra-1" (Sorghum Hybrid 1).

susceptible control. The results confirmed that P-967083, Tetron, and M-90360 have much stronger *Striga* resistance than N-13 or IS-8686, both identified as *Striga-resistant* in many other programs.

Multidisciplinary research. Collaborating with colleagues in the Agricultural Research Corporation (ARC), we have developed an integrated, multidisciplinary research team for research on sorghum breeding, pathology, entomology, agronomy, *Striga* resistance, and food quality. We also are strengthening inter-institutional cooperation with INTSORMIL, West Sudan Agricultural Research Program (WSARP), International Development Research Centre (IDRC), and Ethiopia Sorghum Improvement Program (ESIP).

Pearl Millet Breeding

The pearl millet breeding work was carried out at Wad Medani and E1 Obeid. Wad Medani's 302 mm rainfall in the 1981 season was 61 mm below the long-term average; E1 Obeid's 312.3 mm, 83.7 mm below.

Collection and selection. During 1980/81, we added to our collection 386 new germplasm accessions from Northern Kordofan, west of the Jebel Marra Mountains and eastern Sudan. To create new genetic variability, we made 405 new variety crosses between exotic and local genotypes, selecting exotic germplasm for early maturity, semi dwarfness, synchronous tillering, good head exertion, and yield potential. Local germplasm was to contribute lodging resistance and adaptability; 281 of the 405 crosses were selected to study their F_2 populations. Fifty-one showed high heterosis in the F_1 generation; and we selected 16 hybrids to make synthetics. From the 217 F_2 populations studied, we selected 439 single plants to study their F_3 progenies. Serere composites and Nigerian and Sudanese materials contributed most to the F_2 populations.

The 245 F_3 progenies, 302 F_4 progenies, and 45 F_3 progenies we studied contributed, respectively, 26 F_3s, 16 F_4s, and 1 F_5 progenies to the national yield testing program.

New population development. We now are developing three populations, Intervariety Population (IVP), Bristled Population, and F_2 Bulk Population, and have completed the second cycle of full-sibs progeny selection for IVP. Of the 136 full-sibs tested, 24 were selected at Wad Medani and 13 at E1 Obeid. Average grain yield of the 24 Wad Medani entries was 3836 kg/ha, about 18% higher than the average of the 136 progenies. At E1 Obeid the 1686 kg/ha mean exceeded the mean of the trial by 40%.

The bristled population, through the third random mating, will be mass selected for lodging and drought resistance at E1 Obeid.

The F_2 bulk population was constituted from 600 heads selected from F_2s at Wad Medani and E1 Obeid. Expected to have wider genetic variability, it will be improved initially by mass selection.

National yield trial. A national yield trial with 16 entries (13 ICRISAT selections, 2 controls, and one IVPCI bulk) was carried out at five locations. On the basis of performance estimates, we selected seven genotypes (ICMS 7817, ICMS 7819, IR/IB 7901, SSC A79, SCI K79, SSC K78, and IVS 8206) for retesting in 1982.

Synthetic ICMS 7817, in the national trials since 1979, has averaged 678 kg/ha, about 22% more than Kordofani (local control) and 14% more than Ugandi (a released variety). Farmer-level trials to study ICMS 7817 against a local cultivar and Ugandi are planned.

In the Initial Yield Evaluation Trials (IYET-1, IYET-2), selections from the 1980 breeding nurseries and from regional and international trials and nurseries were tested at Wad Medani, E1 Obeid, and Dimsu. The test entries consisted of 21 selections from the national program, 2 from Niger, and 2 controls. Twenty-four elite genotypes of the international trials were tested against Ugandi. In these trials, 13 genotypes appeared promising at one or more locations and were chosen for the 1982 national trials.

Niger and Senegal improvements. When we evaluated 17 Niger and 15 Senegalese selections, we found ITV 8103 of Niger and IBV 7815, IBV 8103, and IBV 8107 of Senegal useful. IMPS 8020 of the West-African Disease-Resistant Elite-Variety Trial was uniform and agronomically desirable.

We supplied seed of 19 elite selections to ICRISAT breeders in Africa, and received 9 ICRISAT trials and breeding nurseries from ICRISAT Center to evaluate. Of these, SM F_2 populations were most useful and we selected 69 plants to study their F_3 progenies. The crosses P1B 228 x P 339 and P 242 x 3/4 HK were promising at both Wad Medani and E1 Obeid. We selected single plants in three lines of the F_3 Progenies Nursery, and kept Entry 9 (23DBE-20 x Serere 10LB-89-I) of 1981 Uniform Progeny Nursery (UPN 11) for future use.

The millet breeder at Hays, USA, supplied 20 F_1 hybrids, their parents, and six populations. We kept two populations, Senegal Bulk Cross and HMP 559, for further evaluation.

Using the irrigated summer nursery, we increased seed of selected lines and made new variety crosses and synthetics.

Hybridization program. The 1982 crop season was drier than 1981. Rainfall at Wad Medani and E1 Obeid was 56 and 33%, respectively,

Ugandi, a released millet variety that does well in Sudan, is now used in breeding hybrids. Ugandi x *Ex Bornu population hybrids were excellent in 1982 tests.*

below average. Our local millet collection was enriched by an additional 86 entries, collected by Jebel Marra Rural Development Project. Of the 472 local collections evaluated during the crop season, 25 were selected for future use in the breeding program. Locally adapted varieties, Kordofani, Fakiabyad, and Ugandi, were crossed in 131 combinations with the selections of 1981. And 29 new crosses were made between the populations. Two population hybrids—Ugandi x Ex-Bornu and Kordogani x Nigerian Composite gave excellent performance; 63 crosses were selected to study their F_2 populations. About 235 single-plant selections were made from the 301 F_2 populations evaluated at Wad Medani and E1 Obeid. The 812 segregating progenies (F_3 to F_6) gave 14 uniform and high-yielding lines for use in variety crossing, development of experimental varieties, and exchange nurseries. Single plants, however, were selected from 80 other progenies. Two experimental varieties will be produced from the selected lines.

In the Intervariety Population (IVP), 14 full sibs were identified for recombination. The selected full sibs produced 20% more heads per hectare than the mean of 130 entries tested in a replicated trial. Mass selection was carried out in bristled and bulk populations.

A national trial with 21 entries was carried out at five locations. Six cultivars (ICMS 7817, ICMS 7835, IVS P77, IVS H78, IVS 8206 and ITV 8003) were selected for reevaluation.

The 67 newly generated elite products of the hybridization program were tested in three initial yield evaluation trials. Of these 18 genotypes will be reevaluated in 1983. Two experimental varieties, 81 IVPWM22 and 81 IVPWM23, have shown excellent performance for earliness, productive tiller number, and grain yield. They will be included in the final yield trial.

On-farm trials. The Kordofan Regional Ministry of Agriculture conducted on-farm trials at five locations in northern Kordofan. They reported that our variety Ugandi matured 7 to 10 days earlier than the early-maturing local variety at E1 Khassa and 19 days earlier than the late-maturing variety at Babanosa. The yield advantage of Ugandi over the early and late local varieties was 18% and 21%, respectively.

Thirteen genotypes developed in Nigeria were evaluated in Advance Millet Yield Trial 1-82. Two cultivars, INMB 83 and KMDC, were selected for testing in the national program. We supplied seed of 15 elite lines of our program to ICRISAT breeders in Africa.

We completed three international yield trials and evaluated six breeding nurseries and new male-sterile lines along with their maintainers this year. In the Advanced Population Variety Trial, SCI P8001 and SCI P8008 were promising. Elite Variety Trial contributed WC P8004 and IVP P8001 for use in the national program. Two synthetics—ICMS 8146 and ICMS 8135—were selected from the Pearl Millet Advanced Synthetics Trial. Twenty-five dwarf genotypes were tested in the D_2 Dwarf Varieties Observation Nursery and ICMS 8212 was retained.

A total of 571 new variety crosses were made at ICRISAT Center for us by crossing 40 local accessions of Sudan with elite lines of Cameroon, Niger, Nigeria, Upper Volta, Tanzania, Malawi, Kenya, Zambia, and improved varieties of African origin. F_1 hybrids were evaluated this year and 48 crosses were selected to grow in the 1983 crop season.

Among the breeding nurseries six entries of Downy Mildew and Smut Nursery, four lines of Drought Inbred Nursery, and an F_2 population of a cross from ICMS 7835 and ICMS 7703 were promising. One experimental variety SSC P8101 was also selected from the Late Maturity Lines Nursery. Six entries of male-sterile Ex-Bornu were uniform and agronomically acceptable. The combining ability of the selected lines will be studied to identify the best line for future use in the program.

Bayuuda, Kori, and Wad Elhilu were obtained from the southern Darfur region of the Sudan. These entries will be used in our crossing program; we will eliminate unproductive and wild type plants by producing S_1s. Screening against *Striga hermonthica* and downy mildew diseases will be initiated in collaboration with the Western Savanna Development Corporation, from material grown during the 1983 crop season.

Eastern and Southern Africa

ICRISAT Regional Groundnut Program

The ICRISAT Regional Groundnut Improvement Program for southern Africa, established with the Government of Malawi in February 1982, is located at the Chitedze Agricultural Research Station, Lilongwe, Malawi.

The ICRISAT groundnut breeder arrived in September and started plantings in November 1982, using breeding material from ICRISAT Center.

The 5-ha plantings include about 500 germplasm lines, 100 elite parents with disease and insect resistance, 1000 breeding populations (F_2 to F_{10} generations), and 300 breeding lines with resistance to late leaf spot and rust in eight replicated yield trials.

A cooperative trial in the Malawi national program was planted to quantify losses to various diseases.

We planted three line x tester sets to breed for increased size, multiple disease resistance, high yield, quality, and earliness.

An ICRISAT Center pathologist, posted to work in our Malawi program for a season, is combining rust and leaf spot resistance with resistance to rosette virus.

Results of our research and tests in Malawi should be valuable in Tanzania, Mozambique, Zimbabwe, and Zambia, where also groundnut production is important.

Latin America

The primary objective of ICRISATs program at CIMMYT headquarters in Mexico is to develop high-altitude, cold-tolerant sorghum varieties on a global scale with good grain quality. A secondary objective in recent years is to improve genetic material adapted to low and intermediate elevations in Latin America.

ICRISAT began groundnut research plantings in southern Africa in 1982 on 5 hectares at the Chitedze Agricultural Research Station, Lilongwe. Malawi. ICRISAT's plant breeder and plant pathologist will work together in developing groundnuts for southern Africa with multiple disease resistance, high yield, quality, earliness, and increased size.

Development of superior germplasm and source populations with satisfactory adaptation is essential. To achieve that goal, we already have under way integrated and intensive breeding efforts (introductions, conversions, pedigree material, population improvements, and methods to develop hybrids). We are striving for these characteristics: high, stable yield; a range of maturities including early maturity; drought tolerance; and high grain quality.

Our breeding efforts in 1981/1982 for the highland areas included agronomic trials of 11 new sorghum cultivars on farmers' fields and the release of three varieties by the Institute National de Investigaciones Agricolas (INIA) for Mexico.

E1 Salvador released two varieties (CENTA SS-41 and San Miguel No.1) to replace small farmers' local varieties. Both resulted from ICRISAT's breeding material. In Venezuela an ICRISAT variety M 35544, (SC 108-3 x CS 3541) Selection 29-1 is already in 50-hectare seed production.

In Nicaragua, a variety developed from SEPON 77 trial is in production channels, and in Guatemala several ICRISAT food-type varieties (M 91010, M 91060, M 91057, SPV-352, M 90906, and M 90970) outyielded Guatemala's best hybrid and are being increased in large plots. In Haiti eight ICRISAT varieties are being increased for multilocation testing on farmers' fields.

ICRISAT's team in Mexico has identified sorghum lines suitable for tortillas *and is improving them in cooperation with that country's national grain quality laboratory.*

ICRISAT signed an official agreement with Mexico for closer cooperation on all five mandate crops.

Joint ICRISAT/INTSORMIL sorghum workshop for Latin America. This annual workshop at CIMMYT headquarters in Mexico for Latin American sorghum scientists was jointly hosted by ICRISAT and INTSORMIL. At this year's workshop participant scientists observed and selected new genotypes generated by ICRISAT and INTSORMIL, reviewed current knowledge of factors affecting food quality of sorghum in the Americas, and instructed sorghum workers in Central America and Mexico on using simple techniques to select sorghum with better food quality.

CLIAS (Comision Latinoamericana de Investigadores en Sorgo). Our breeder organized a field day in Guatemala for national coordinators from Central America, CATIE, and INTSORMIL representatives to set priorities on problems of small farmers in each country and to initiate agronomic trials for cropping systems involving sorghum.

Trials. The following sorghum trials were from CIMMYT: Cold Tolerant Sorghum Adaptation Nursery (CTSAN), Latin American Sorghum Observation Nursery (LASON), Latin American Sorghum Elite Variety Yield Trial (LASEVYT), and Latin American Sorghum Drought Tolerant Yield Trial (LASDTYT).

Training. Training personnel from the national programs is an important function of the ICRISAT program at CIMMYT. The ICRISAT breeder has trained 15 scientists in sorghum improvement. Much of ICRISAT's impact in Central America stems from making superior germplasm available and training scientists from national programs.

Awards. ICRISAT received two recognitions in 1981/82 for its work on sorghum in Mexico, Central America, and the Caribbean. One was general recognition from 10 countries in the region for training, making breeding stocks available to national programs, and periodic visits by ICRISAT scientists to national programs. The other was a certificate for releasing two varieties, CENTA SS-41 and San Miguel No.1, in El Salvador.

Food quality sorghum lines suitable for tortillas have been identified and are being improved in cooperation with INIA's grain quality laboratory.

An agronomist joined the ICRISAT team for Mexico, Central America, and the Caribbean 1 September 1982 and was named coordinator of agronomy for the Latin American Commission of Sorghum Investigators (CLAIS), a regional body recently formed in Guatemala by ICRISAT staff with the help of national sorghum coordinators and scientists of the region. He traveled throughout the sorghum-growing areas of the region to become familiar with research needs and with farmers, scientists, and administrators. Contacts were made with INTSORMIL and CATIE for future collaborative research.

During 1983 the agronomist will concentrate on sorghum-based, cropping-system investigations in farmers' fields in eight countries. Using new sorghum cultivars developed in Mexico, he will initiate field testing in different agro-ecological zones under different farming systems as a prerequisite for introducing the cultivars to farmers. Managing sorghum in droughty areas and on steep slopes of Central America's rugged mountains also will receive attention.

ICRISAT's breeder and agronomist together will train young scientists at ICRISAT's CIMMYT base and supervise in-service country training. Our agronomist also will advise national programs on sorghum production at the farmer level.

Cooperation with ICARDA

Plant Improvement

The objectives of the breeding program remain: to incorporate ascochyta blight resistance, cold tolerance, and near-insensitivity to photoperiod into high-yielding kabuli backgrounds of variable stature and seed size for spring and winter sowing in the Mediterranean region of western Asia, northern Africa, southern Europe, and the Americas.

On-farm trials and cultivars' release. For the third season, the on-farm trials demonstrated superior yields from winter sowing. Yields of ILC-482 sown in winter were 74% better than yields from its spring sowing, and double those of a spring-sown Syrian Local (Table 16). The data on ILC-482 led the Syrian Ministry of Agriculture to release it for general cultivation in the drier zones of Syria that receive less than 400 mm of annual precipitation.

Also 2 years of on-farm trials in Jordan led to prerelease, large-scale multiplication of a second cultivar, ILC-484.

Table 16. Seed yields (kg/ha) of ILC 482 and Syrian Local chickpeas in on-farm trials in Syria for three crop years.

	Seed yields (kg/ha)[1]			% increase of ILC 482 over spring-sown Syrian Local	
	ILC-482		Syrian Local		
Season	Winter	Spring	Sown in spring	Winter	Spring
1979/80	1840		970	90	
1980/81	1690	960	650	160	48
1981/82	1260	880	630	100	40
Mean	1600	920	750	110	44[a]

1. Means of 18, 24 and 20 locations in the three crop years.
a. Based on two crop years, 1980/81 and 1981/82 only.

On-farm trials in Lebanon and Morocco have been encouraging and will be continued in 1982/83.

International nurseries and trials. In 1981/82, 302 sets of nine types of nursery covering yield, segregating material, and disease were distributed to 33 countries, a marked increase over previous years. Data received thus far indicate pronounced interactions between entries and locations.

In the 1980/81 spring-sown Chickpea International Yield Trial (CIYT), ILC-576 was the highest yielder overall and ranked among the top five entries in 6 of 20 tests. In the winter-sown trial (CIYT-W), ILC-484 and ILC-482 again were the highest yielders, with ILC-482 among the top five entries in 9 of 12 countries. In the large-seeded cultivars (CIYT-L) trial, ILC-464 and ILC-604 appeared in the top five entries at 7 of 17 locations. The F_3 and screening nurseries were to provide early and advanced segregating material to the national programs for selections under their conditions. The results of the ascochyta blight nursery are described in a later section.

Hybridization. To develop materials for winter and spring sowing and large-seeded and tall types, we made 8 crosses, including 319 two-way, 32 three-way, and 34 backcrosses. Additionally, we made a few crosses specially for the Jordan and Pakistan national programs to incorporate *Ascochyta* resistance into desi materials for Pakistan, India, Iran, and Ethiopia.

Breeding strategy. Since *Ascochyta* resistance is now considered mandatory, we sow early generations of all breeding materials in winter for more effective screening. Winter sowing also enables us to select for cold tolerance and facilitates off-season (summer) advancement. Off-season sowing also helps eliminate highly photosensitive segregants.

From F_5 on, progeny rows are winter- and spring-sown at Tel Hadya and Terbol, while single-plant selection and bulking are carried out in all four environments. After further replicated tests in the same environments, promising materials are included in international nurseries. Numbers of F_1 to F_6 generation progenies and bulks grown in this system during 1981/82 are shown in Table 17.

Table 17. The numbers of F, and more advanced chickpea progenies and bulks grown for winter (W) and spring (S) sowing and for large-seeded (L) and tall types (T) in the main and off-seasons in Syria, 1981/82.

	No. of populations/ progenies			No. of plants selected			No. of progenies bulked		
Generation	Main season (Tel Hadya)	Off-season (Terbol)	Total	Main season (Tel Hadya)	Off-season (Terbol)	Total	Main season (Tel Hadya)	Off-season (Terbol)	Total
F_1	45	349	394	0	0	0	0	0	0
F_2 Populations	269	9	278	2940	0	2940	0	0	0
F_3 Populations	51	0	51	0	0	0	0	0	0
Progenies	351	1595	1946	1091	910	2001	0	0	0
F_4 S + W	1282	653	1935	1355	450	1805	18	23	41
L	1	16	17	6	69	75	1	0	1
T	9	0	9	33	0	33	6	0	6
F_5 W	1987	1765	3752	2945	0	2945	148	170	318
S	532	0	532	0	0	0	23	0	23
L	122	1	123	61	4	65	18	1	19
T	17	2	19	24	0	24	7	2	9
F_6 W	2484	4	2488	2232	0	2232	132	1	133
S	2324	0	2324	0	0	0	36	0	36
L	4	0	4	0	0	0	0	0	0
T	12	7	19	24	0	24	6	7	13

Table 18. Seed yields (kg/ha) of chickpea exceeding the yields of the best check in preliminary yield trials in the spring at Tel Hadya, Syria, 1981/82.

Trial 1		Trial 2		Trial 3		Trial 4	
Entry	Seed yield	Entry	Seed yield	Entry	Seed yield	Entry	Seed yield
FLIP 81096	1990	FLIP 8119	2190	FLIP 81146	2200	FLIP 81166	2120
81095	1970	81131	2180	81149	2100		
81097	1910	81130	2170				
81093	1890						
81104	1740						
81105	1690						
81102	1630						
ILC 263	1630	ILC 263	2030	ILC 263	1640	ILC 263	2000
1930	1610	1930	1840	1930	1650	1930	1430
1929	1340	1929	1780	1929	7030	1929	1870
SE	±167		±195		±221		±177
CV (%)	15		20		22		18

Trial 6		Trial 7		Trial 9		Trial 10	
Entry	Seed yield	Entry	Seed yield	Entry	Seed yield	Entry	Seed yield
FLIP 81208	2020	FLIP 81229	2190	FLIP 81251	2210	FLIP 81296	2380
81218	1980	81230	2030	81254	2150		
81204	1940	81225	200	81253	2070		
				81250	2000		
				81252	1840		
				81255	1840		
ILC 263	1920	ILC 263	1970	ILC 263	1820	ILC 263	1870
1930	1170	1930	1530	1930	1280	1930	1930
1929	1180	1929	1840	1929	1360	1929	2250
SE	±177		±138		±185		±166
CV (%)	20		14		19		16

Breeding for spring sowing. We tested 231 breeding lines in 11 preliminary yield trials and 42 entries in 2 advanced yield trials at Tel Hadya and Kfardan, using two local cultivars—ILC-1929 from Syria and ILC-1930 from Lebanon—and one improved cultivar, ILC-263, as checks. At Tel Hadya, 24 entries yielded more than ILC-263 in eight of the preliminary trials (Table 18), but no test entry exceeded ILC-263 in the other three trials. The highest yield (2380 kg/ha) was 74% better than the best check. In the advanced trials, six entries yielded more than the best check (Table 19). Unexpected events prevented harvest at Kfardan.

Breeding for winter sowing. We evaluated 126 breeding lines at Tel Hadya and Kfardan in six winter-sown preliminary yield trials with three checks; ILC-3279, ILC-482, and ILC-1929. At Tel Hadya, 10 entries yielded more than the best check, ILC-3279 (Table 20). Ascochyta blight killed ILC-1929 in all trials. FLIP 81-347 yielded 3540 kg/ha, highest ever recorded at Tel Hadya. Unexpected events at Kfardan prevented us from harvesting there.

Using the same three checks, we also tested 63 breeding lines in three winter-sown advanced yield trials at Tel Hadya, Lattakia, and Terbol. Six lines at Tel Hadya, 30 at Lattakia, and 35 at

Table 19. Seed yields (kg/ha) of chickpea entries exceeding the yield of the best check in advanced yield trials at Tel Hadya, Syria, 1981/82.

Trial 1		Trial 2	
Entry	Grain yield	Entry	Grain yield
FLIP 81395	1690	FLIP 81003	1670
ILC 3110	1690		
ILC 657	1690		
ILC 3110	1690		
ILC 3119	1670		
ILC 263	1540	ILC 263	1640
ILC 1930	1640	ILC 482	1560
ILC 1929	1580	ILC 1929	1500
SE	±85		±81
CV (%)	11		12

Terbol had good *Ascochyta* resistance and cold tolerance, and yielded more than the best checks. All newly bred lines had more acceptable seed quality than the best check, ILC-3279. The five highest yielding entries are shown in Table 21. To our knowledge, the 5890 kg/ ha yield of FLIP 81-60W at Lattakia is the highest ever reported for chickpea. The best entries will be included in the 1982/83 international nurseries.

Breeding for large seed. We compared large-seeded lines from the germplasm and breeding materials with ILC-1929 in a spring-sown preliminary yield trial at Tel Hadya. Several entries combined greatly improved seed size with yields equalling those from checks (Table 22). They will be included in international trials in 1982/83.

Breeding for tall-plant type. In an advanced yield trial of 24 tall types at Tel Hadya, ILC-72, ILC-202, and ILC-3279 combined high yields with high resistance to cold and ascochyta blight. We identified several promising lines from 32 entries in a replicated row trial.

Ascochyta blight resistance in desi types. In collaboration with ICARDA, we furnished 11 F_3 populations to four locations in Pakistan, and we evaluated 17 F_2s from ICRISAT at Tel Hadya. All the F_2 plants were susceptible, but 420 resistant ones were selected in four populations of crosses made at ICARDA. Some seed of the single plants was received at ICRISAT for performance tests; the remainder will be screened again at Tel Hadya to identify resistant progenies.

Cold tolerance. Sub-zero temperatures were recorded 31 nights during 1981/82 at Tel Hadya, more than in previous years; the resulting plant mortality emphasized how important cold tolerance is in winter-sown crops.

Table 20. Seed yields (kg/ha) of chickpea entries exceeding the yield of the best check in Preliminary Yield Trials-Winter at Tel Hadya, Syria, 1981/82.

Trial 1		Trial 2		Trial 3		Trial 4		Trial 6	
Entry	Grain yield	Entry	Grain yield	Entry	Grain yield	Entry	Grain yield	Entry	Grain yield
FLIP 81293	3040	FLIP 81312	2700	FLIP 81-347	3540	FLIP 81362	3050	FLIP 81372	2410
81304	3010			81-341	3100				
81292	2880			81-335	3100				
				81-343	2930				
ILC 482	980	ILC 482	1210	ILC 482	810	ILC 482	710	ILC 482	1250
3279	2760	3279	2680	3279	2700	3279	2610	3279	2210
SE	±147		±269		±179		±204		±297
CV (%)	15		27		18		29		40

Table 21. Seed yields, disease resistance, and cold tolerance characteristics of chickpea lines in winter-sown advanced trials at Tel Hadya, Lattakia, and Terbol, Syria, 1981/82.

Trial No.	Entries	Seed yield (kg/ha)				Asco. blight[1]		
		Tel Hadya	Lattakia	Terbol	Mean	Veg.	Pod	Cold Tol.[2]
1	FLIP 81-10W	2270	3650	2430	2780	3.3	5.3	4.3
	FLIP 81-3W	2300	3310	2700	2770	3.8	6.0	4.3
	FLIP 81-11W	1710	3490	2850	2680	4.5	6.8	5.0
	FLIP 81-12W	1240	3820	2800	2620	4.3	7.3	5.5
	FLIP 81-15W	1630	3980	2190	2600	4.0	6.0	6.0
	Checks ILC 482	620	3110	2660	2130	4.8	7.5	5.5
	ILC 3279	2280	2860	2690	2610	2.0	2.0	4.8
	ILC 1929	0	0	2140	-	9.0	-	8.5
	SE	±161	±408	±189				
	Trial mean	1000	2860	2450	2100			
	CV (%)	29	29	15				
2	FLIP 81-41W	2180	4520	2790	3190	3.0	3.3	4.8
	FLIP 81-37W	1720	4910	2160	2930	3.5	5.8	5.3
	FLIP 81-27W	1690	4230	2630	2850	3.3	4.0	6.3
	FLIP 81-35W	1550	4450	2480	2830	4.0	6.3	5.8
	FLIP 81-24W	1310	4610	2490	2810	5.3	7.0	6.3
	Checks ILC 482	480	4580	2390	2480	5.7	8.0	6.7
	ILC 3279	1840	2890	2310	2350	2.0	2.0	4.8
	ILC 1929	0	0	2410	-	9.0	-	8.0
	SE	±129	±424	±126				
	Trial mean	1430	4000	2370				
	CV (%)	18	21	11				
3	FLIP 81-60W	1360	5890	2920	3350	4.5	7.0	4.8
	FLIP 81-56W	2690	4130	2810	3210	3.0	4.3	4.3
	FLIP 81-43W	1490	5180	2550	3070	4.0	7.0	6.3
	FLIP 81-57W	1900	4950	2880	3040	3.0	4.8	5.5
	Checks ILC 482	490	4680	2170	2450	4.8	7.7	6.2
	ILC 3279	2430	4540	2670	3210	2.0	2.0	4.5
	ILC 1929	0	0	2260	-	9.0	-	8.0
	SE	±158	±369	±207				
	Trial mean	1240	4480	2250				
	CV (%)	25.5	16.5	18.4				

1. Asco. blight = Ascochyta blight disease, scoring done on 1-9 scale where 1 = free and 9 = complete mortality.
2. Cold tolerance, scoring done on 1-9 scale where 1 = free and 9 = complete mortality.

Table 22. Seed yields and seed weight of the five top yielding entries in the Preliminary Yield Trial of large seeded types at Tel Hadya, Syria, 1981/82.

Entry	Seed yield (kg/ha)	100-seed wt.(g)
ILC 1795	2340	48
FLIP 81-181	2270	43
FLIP 81-176	2250	41
ILC 76	2180	45
FLIP 81-178	2160	41
Check ILC 1929	2060	35
SE	±198	
CV(%)	17	

More than 10 000 lines (5484 desi and 1286 kabuli accessions, 387 entries in yield trials, and 3643 advanced breeding lines) were screened for cold tolerance. The results are presented in Table 23. Desi types appeared to be more cold tolerant than kabuli types.

Genetic Resources

Evaluated data and passport information for 3300 kabuli germplasm accessions have been computerized, and a catalog is ready to be printed and distributed.

In 1981/82, we evaluated 1000 accessions under winter-sown conditions, and screened the accessions for resistance to leaf miner, *Orobanche, Bruchus* sp., ascochyta blight, and for cold tolerance.

Diseases

Ascochyta Blight

Ascochyta blight caused considerable damage to commercial crops of Syria, Tunisia, and Morocco. We have observed sclerotinia stem rot and fusarium and rhizoctonia root rots but only at low incidence, probably due to low temperatures. Stunt, caused by pea leaf-roll virus, was observed in most chickpea-producing areas and a complex, possibly of pea streak and bean yellow mosaic viruses, severely damaged winter-sown chickpea at Beja, Tunisia.

Screening for resistance. During the past four seasons, we screened 13 410 desi and kabuli germplasm accessions at Tel Hadya, using the debris method of inoculation. Lines that showed resistance during the vegetative phase later developed severe pod infection. Ten kabuli accessions (ILC-72, -196, -201, -202, -2506, -2956, -3274, -3279, and -3246; and PCh-128) had vegetative-phase ratings of 1-4 (less than 15% pod infection). Seven desi accessions (ILC-3034, -4200, -4248, -4368, -5124, -6202, and -6981) also were resistant (less than 15% pod infection) during the vegetative phase.

International nurseries. During the past four seasons, chickpea international ascochyta blight nurseries (CIABN) have helped identify resistance to *Ascochyta* in several countries, and the data indicate several strains of the pathogen. Isolates from western Asia and northern Africa, where both Kabuli and desi genotypes remain resistant, seem to be less susceptible than those

Table 23. Results from screening chickpea germplasm accessions, cultivars, and advanced breeding lines for cold tolerance at Tel Hadya, Syria, 1981/82.

Scale	Germplasm acc.		Yield nursery		Breeding line	
	Desi	Kabuli	Kabuli	% of total	No.	% of total
Highly tolerant	1778	30	0	25.3	0	0.0
Tolerant	1428	365	13	25.7	114	3.1
Intermediate	1399	687	220	32.3	3088	84.8
Susceptible	624	198	121	13.2	410	11.2
Highly susceptible	255	6	33	4.1	31	0.9

from the Indian subcontinent, where only the kabuli types are resistant. Six kabuli types (ILC-72, -202, -2380, -2956, and -3279 and PCh-128) maintained high resistance in most environments.

Chemical control. Seed dressing with Calixin-M® (11% tridemorph + 36% maneb, alone or in combination with benomyl), at 0.3% eradicated the pathogen from seed of susceptible and tolerant cultivars with deep lesions. Higher doses (0.6%) were more effective but caused delayed germination and initial leaf malformation and reduced growth.

The foliar application of chlorothalonil, alone or alternating with Calixin M® (17 sprays at 1.5 g/liter at 7- to 10-day intervals) almost completely protected a highly susceptible cultivar sown in winter under artificial epiphytotic conditions, indicating excellent potential for that foliar fungicide. Calixin M® also gave satisfactory control.

Epidemiology. Artificial inoculation studies indicated that *Pisum sativum, Phaseolus vulgaris,* and *Vigna unguiculata* can be infected by the pathogen.

We observed chlamydospore-like structures in *A. rabiei* cultures maintained in ambient temperatures, also saprophytic colonization of food and forage legume straw, including faba beans and lentils.

Table 24. Reactions of chickpea cultivars to three isolates of *Ascochyta rabiei* collected at Tel Hadya, Syria.

	Blight score[a]		
Cultivar	TH-1	TH-2	TH-3
ILC 194	4	4	4-6
ILC 249	3	8	8
ILC 482	3	6	8
ILC 3279	3	3	8
ICC 3996	2	2	4

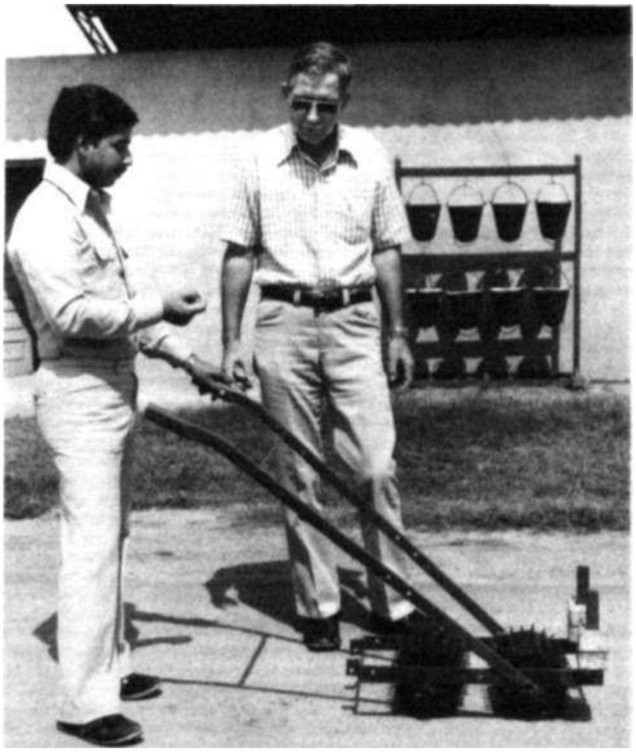
a. 1 = free; 9 = complete mortality.

Variability in *A. rabiei.* Three isolates that we collected at Tel Hadya vary in pathogenicity. TH-1, isolated in 1978/79, appears less pathogenic than TH-2, isolated in 1979/80 (Table 24). ILC-3279 and other lines that resist TH-1 and TH-2 are susceptible to the TH-3 we collected from infected ILC-482 in 1980/81. ILC-194 and ICC-3996 were moderately resistant to TH-3.

Cultural practices. Sowing infected seed 10 cm or deeper eradicated seedling infection, and burying diseased debris 10 cm below soil surface prevented disease transmission. But applying NPK did not affect disease development.

Training

A total of 126 agricultural scientists and technical assistants from 35 countries participated in training programs at ICRISAT Center during 1982 (Table 25).



Equipment designed and developed by a research fellow (left)—in consultation with ICRISAT engineers—to improve plant stands informers' fields.

ICRISAT scientist (left) supervises on-farm research conducted by an international intern.

As a Ph.D. thesis problem, a research scholar (left)— watched by ICRISAT scientists—spreads genes of wild millet species into the gene complex of cultivated varieties to identify improved plant characters.

Post-doctorate programs. The post-doctorate programs provided 78 man-months of research training for international interns and 69 man-months for research fellows. Their research problems related to breeding and selecting genotypes with increased yield potentials to stabilize production under adverse soil and environmental conditions. They studied genotype-by-environmental interactions to identify selections with wider adaptation—also inheritance of grain mold resistance and drought tolerance. On-farm research was conducted to evaluate methods suitable for transfering technology to farmers.

Post-doctoral scholars used the electron microscope in research to identify and study legume viruses.

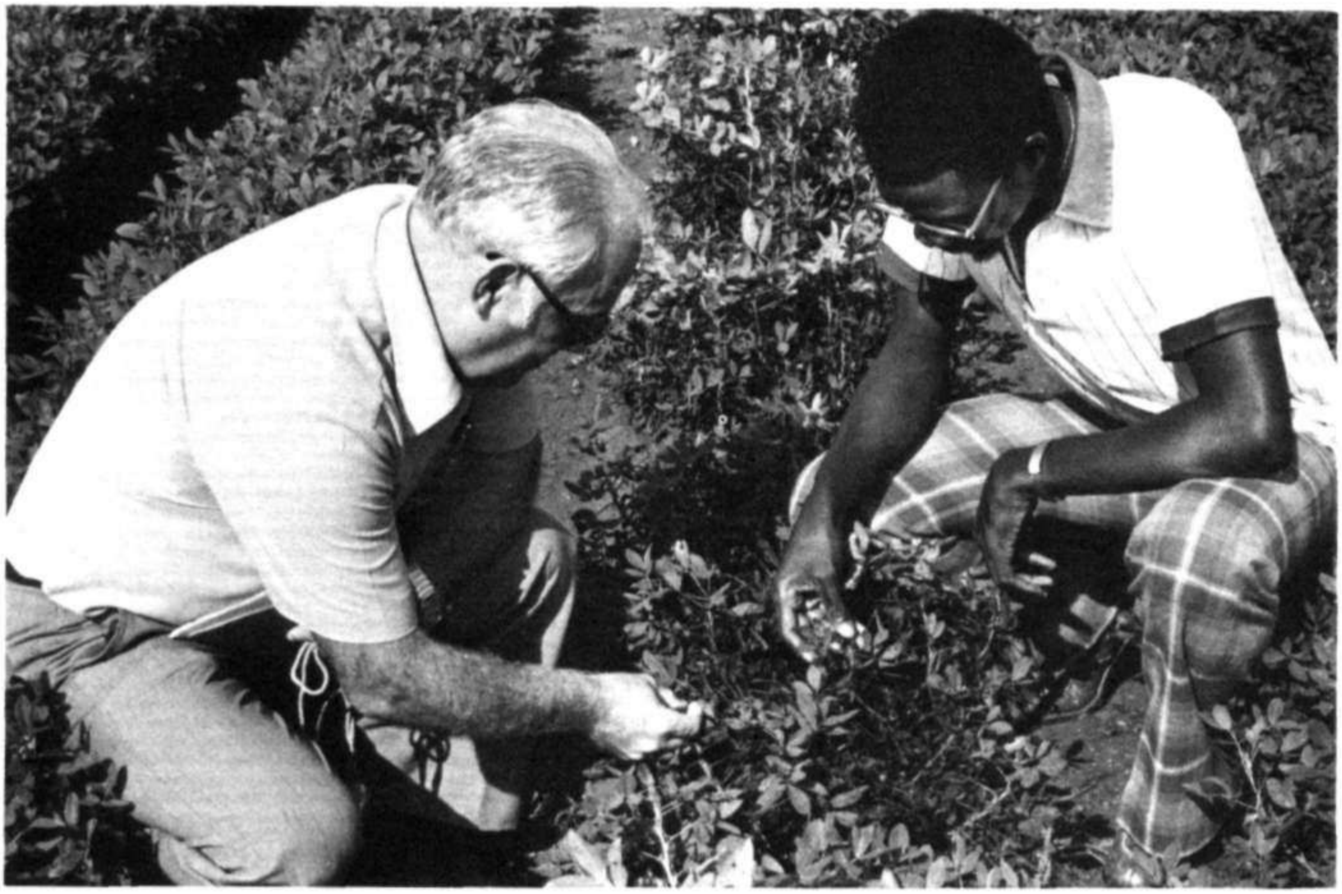
Table 25. Number of participants—by country—who completed a long-term training program in 1982.

Country	Number
Bangladesh	5
Benin	4
Botswana	3
Brazil	2
Cameroon	3
Chile	1
China	5
Ethiopia	2
Fiji	2
Gambia	4
Ghana	4
Guinea	4
India	17
Indonesia	3
Japan	1
Jordan	1
Kenya	5
Lesotho	2
Malawi	4
Mali	7
Nepal	1
Netherlands	1
Niger	1
Nigeria	2
Pakistan	5
Senegal	6
Sudan	7
Tanzania	1
Thailand	3
Turkey	3
Uganda	3
Upper Volta	5
USA	7
Zambia	I
Zimbabwe	1
Total	126

Thesis research. Thirty-two students from 12 universities and 11 countries participated in 237 man-months of thesis research for PhD and MSc degrees under the guidance of ICRISAT scientists. Students studied the potential use of wild species of sorghum and millet in an introgression program to increase resistance to disease and insects and yield potentials of selected cultivated varieties. Other thesis research included studies of iron chlorosis in groundnuts and breeding for resistance to wilt in pigeonpeas and chickpeas.

The fellow program. The in-service fellow program was initiated to provide opportunities for employed research scientists with experience in the semi-arid countries to obtain intensive training in their research specialities. Seven fellows from four countries participated in 10 man-months of this specialized skill development.

In-service training. The annual six-month in-service training program for scientists and technical assistants accommodated 91 persons from 29 countries in more than 494 man-months of research and extension-methods training. More than 90 ICRISAT research scientists assisted in the training programs. Subjects covered were crop improvement, crop production, experimental design and methods, agronomy, entomology, pathology, microbiology, physiology, soil fertility, land and water management, cropping systems, economics, agroclimatology, nursery management, research management, and extension methods training.



An in-service fellow (right), at ICRISAT for a short term of intensive study, observes groundnut plants with ICRISAT pathologist.

Table 26 lists by category those in training during 1982.

Short-term training. Short-term training programs on how to improve deep-Vertisol cropping during the rainy season were conducted for policy makers, scientists, and bank agricultural officers who are to be associated with on-farm research in India. These 2-day to 3-week programs involved selecting and designing cropping systems, the procedure for developing a watershed, and how to help farmers use their resources to increase crop production and improve their welfare. A special 1-week training and planning program in agrometeorology of sorghum and millet in the semi-arid tropics was conducted by the Farming Systems Research Program staff and The World Meteorological Organization for 17 scientists from 11 countries.

Our alumni. Many persons who have completed training since 1974 are now serving as station research managers, leaders of research teams, research farm managers, field technicians, and extension agents. And many have

Table 26. Number in training at ICRISAT Center during 1982.

	Completed	Continuing
In-service Trainees	91	2
Research Scholars	16	16
In-service Fellows	7	0
Research Fellows	6	5
International Interns	5	5
Apprentices	1	0
Total	126	28

In-service trainees develop skills in research techniques, aided by an ICRISAT training officer.

been selected for additional academic training.

Requests for recent publications from our alumni, visits from them, and reports by ICRISAT scientists returning from cooperating countries all indicate that former trainees are active and successfully participating in responsible positions for which they received training at ICRISAT.

Workshops, Conferences, and Seminars

Second Policymakers' Seminar to Review the Program of the Improved Vertisols Management in relation to Assured Rainfall Regions of India. This seminar was conducted at ICRISAT Center 10-11 September to compare and exchange information gained in the various on-farm verification trials conducted or under way in the states of Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra as part of Phase-I (1981-83) of the action plan approved at the First Policymakers' Seminar held in Delhi on 21 May 1981. The seminar was also intended to formulate specific proposals for Phase 11 of the previously proposed action plan for the 1983-86 period. Participating were 38 officers and representatives of the Ministry of Agriculture, Government of India, the states of Madhya Pradesh, Karnataka, Andhra Pradesh, and Maharashtra, credit institutions, and 1CAR and ICRISAT. The seminar included field visits to the operational experiments on the Vertisols watershed at ICRISAT Center and to on-farm research trials at Taddanpally/ Sultanpur, about

42 km northwest of Patancheru. The summary of proceedings of the seminar is available from the Farming Systems Research Program, ICRISAT.

Working Group Meeting on Control of *Striga* in Sorghum. This meeting was jointly sponsored by the All India Coordinated Sorghum Improvement Project and ICRISAT, 30 September to 1 October, at ICRISAT Center. The meeting was attended by 31 scientists involved in *Striga* research in India, to review the present status and decide the thrust of work required to solve the problem.

The meeting was divided into five sessions: problems of *Striga* were outlined; available information in respect of breeding, agronomy, and biological control measures was reviewed; presentations were made on location-specific studies conducted on *Striga* control, on the mechanism and genetics of *Striga* resistance, and on screening technique and host-parasite interaction; breeding and agronomy groups separately discussed future course of work and formulated suitable proposals; and in a concluding session, future research needs and goals were outlined, keeping in view the recommendations from the breeding and agronomy groups. Participants visited the ICRISAT *Striga* laboratory and fields and also fields of the All India Coordinated Research Project for Dryland Agriculture at Hayatnagar on 1 October.

Salient points from the presentations in the meeting are summarized in the proceedings available from the Sorghum Improvement Program, ICRISAT.

Joint ICRISAT/WMO Symposium and Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics. Agriculturists and climatologists from 18 countries joined ICRISAT scientists to discuss how climatology can be put to better use in improving sorghum and millet production.

The planning meeting and international symposium were sponsored mainly by ICRISAT and the World Meteorological Organization (WMO), an agency of the United Nations. Other co-sponsors were the Food and the Agricultural Organization of the UN (FAO), INTSORMIL, a program of international research on sorghum and millet sponsored by the US Government, and Texas A & M University, USA.

There were 112 participants in the sessions, which began with a series of planning meetings 8 November and ended with a 5-day symposium 15-19 November at ICRISAT Center.

Participants reviewed the present state of knowledge regarding agroclimatological factors influencing the growth and development of sorghum and millet, and identified the gaps, current needs, and future perspectives in research on how weather affects these crops.

The proceedings of the symposium are in preparation and will be available from Information Services, ICRISAT.

Second Village-Level Studies Workshop. The Second Village-Level Studies Workshop, jointly sponsored by ICRISAT and Gujarat Agricultural University, was held at Anand Campus of Gujarat Agricultural University 26-29 April. A total of 32 participants from Gujarat Agricultural University, Agro-Economic Research Centre, Vallabh Vidyanagar, Gujarat, Jawaharlal Nehru Krishi Vishwa Vidyalay, Jabalpur, Madhya Pradesh, and ICRISAT took part in this workshop.

The workshop provided an opportunity to participating scientists to understand major problems in the semi-arid tropical (SAT) areas of Gujarat. It should help in designing a new technology acceptable to farmers and in exploring new areas for research.

Chickpea Breeders' Meet. The annual Chickpea Breeders' Meet was held from 4 to 6 February at ICRISAT Center, and 13 Indian scientists participated. A field tour was organized to show them the experimental plots of various chickpea subprograms, farming systems, and germplasm at the Center. Points of common interest to ICRISAT and Indian national chickpea programs were discussed. The Indian scientists also selected materials from ICRISAT breeding plots for use in their own programs.

Participants in the symposium on agrometeorology (held 15-19 Nov) hear about an ICRISAT experiment. Agriculturists and meteorologists from 18 countries jointed ICRISAT scientists to discuss how climate studies can be better used to improve production of sorghum and millets.

Millet Field Days. Some 26 scientists from different parts of India and from ICRISAT participated in pearl millet field days on 20 and 21 September at Hissar. The Indian scientists selected material from ICRISAT plots for trials in their locations.

Early Maturity Pigeonpea Breeders' Meet. The ICRISAT-HAU Early Maturity Pigeonpea Breeders' Meet was held at Hissar 18-20 October, in cooperation with the Plant Breeding Department of Haryana Agricultural University. Some 30 persons attended, including 19 pigeonpea breeders from the Indian national program, one from Australia, a trainee from Kenya, 3 ICRISAT staff located at Hissar, and 6 ICRISAT Center staff members.

Medium and Late Maturity Pigeonpea Breeders' Meet. The annual Medium and Late Maturity Pigeonpea Breeders' Meet was held 6 to 8 December at ICRISAT Center. Thirteen pigeonpea breeders from the Indian national program and a breeder each from the Hindustan Lever Research Foundation and the Mahyco Seed Company, Jalna, Maharashtra, attended. The participants visited the pigeonpea subprograms at the Center and discussed points of common interest. They selected material from the ICRISAT breeding program for their own use, and participated in a seminar led by Dr. S.M. Virmani, Leader, Farming Systems Research Program, on "Role of Pigeonpea in Production Technology of Deep Vertisols."

Farmers' Field Days. About 150 farmers participating in ICRISAT's village-level studies-drawn from Aurepally (Andhra Pradesh), Shirapur and Kanzara (Maharashtra)—were taken on field visit to Dindi Agricultural Farm, Satara, and Chandrapur Agricultural Research Stations in Maharashtra during November and December. This gave them an understanding of the cropping patterns used at these reseach stations.

Visitors' Services

We received 8935 visitors to ICRISAT Center in 551 groups averaging about 10 groups a week during 1982. Farmers continued to be the largest number (2982) of visitors as in previous years. They were enthusiastic about technological advances made here and many expressed hope for great change in their traditional agriculture. A farmers' day was organized 3 October 1982, when 1600 farmers visited the ICRISAT Center; 67 blind trainee-farmers among the visitors examined the crops using their strong sense of touch.

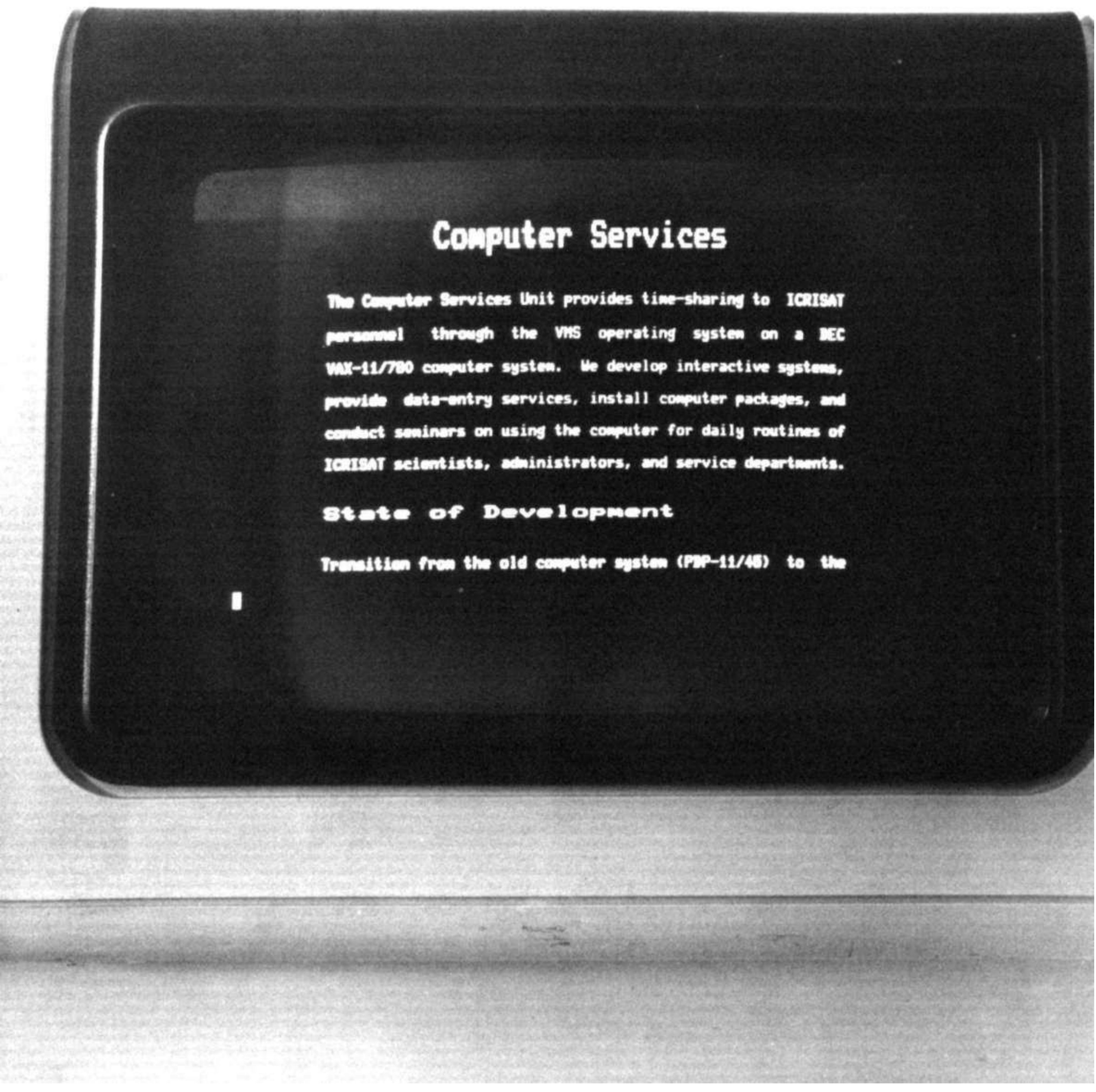
The next biggest group (2345) was comprised of students, mostly agriculture students. The other groups consisted of eminent scientists, diplomats, extension personnel, administrators, representatives of various communications media and the general public.

Publications

Conference Paper

SINGH, K.B., and ERSK1NE, W. 1982. Breeding of food legume with particular reference to chickpea and lentil. Paper presented at the symposium: The Interfaces between Agriculture, Food Science, and Human Nutrition in the Middle East, sponsored by ICARDA and UNU at ICARDA, 21-25 Feb 1982, Aleppo, Syria.

RESEARCH SUPPORT ACTIVITIES



Contents

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RESEARCH SUPPORT ACTIVITIES

Plant Quarantine

Export of Plant Material

During the year, 60 220 seed samples of sorghum, pearl millet, pigeonpea, chickpea, groundnut, and minor millets were examined. Healthy selected seeds were treated with appropriate insecticides and fungicides in ICRISAT's Quarantine Laboratory as required by importing countries.

All seed materials certified as free from pests and diseases by the plant quarantine authorities of the Government of India were exported to scientists and other cooperators in 86 countries. The material exported included seeds from breeding nurseries, yield trials, pest and disease nurseries, genotypes for chemical analysis, and germplasm accessions from ICRISAPs gene bank. We also subjected the following samples to thorough quarantine examination for export: 195 seed samples of *Heteropogon,* maize, and *Atylosia;* 237 of sorghum for ergostrol estimation; 590 of ground sorghum plant material; 8 of sorghum flour, 51 unrooted cuttings of wild *Arachis* species, and 115 *Rhizobium* cultures of chickpea, pigeonpea, and groundnut.

In addition, three samples of mung bean were cleared by the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, for export to the Peoples' Republic of China. Full details are presented in Table 1.

Table 1. Plant material exports during 1982.

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
AFRICA							
Botswana	188		23				14
Burundi	54		19	20	19	25	
Cameroon	148	438	23	52	108		
Egypt	199			224	18		
Ethiopia	1036			372	212		14
Gambia	69		9				
Ghana		4	10	4	64		14
Ivory Coast	47		5		33		
Kenya	487		109	456	43		
Lesotho	44						
Libya		5					
Malawi	272	3	170		2198		7

Continued.

Table 1. *Continued.*

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
Mali	1100	57	162		215		
Morocco				48			
Mozambique	354		3		33		28
Niger	976	5788			45	1	1
Nigeria	239	474					
Rep. du Benin		20			84		
Rwanda	138	35	31		18	25	
Senegal	1150	257					
Sierra Leone			23		67		
Somalia	2367						
South Africa			23				
Sudan	518	1082	226	250	250	4	
Tanzania	326	49		64	660		
Tunisia				187			
Uganda	1196	4				598	14
Upper Volta	1584	334			41	20	
Zaire	24		29				28
Zambia	719	101		165	80		
Zimbabwe	793				1		3
ASIA							
Bahrain	20						
Bangladesh	12		92	823	79		3
Burma	69			134			
China	4419		20	86	27		
Indonesia			66		60		6
Iraq	58			224			
Japan	671		7	9	6		8
Jordan				6			
Malaysia	58		34				
Maldives			20				
Mauritius			22	42	39		
Nepal	69		20	353	23		
Pakistan	566	59	538	1967	334		
Philippines	184	32	227	282	168		5
Saudi Arabia	25	1	24		90		
South Korea					62		
Sri Lanka	69		20			199	
Sultanate of Oman	69	5		120	44		
Syria				119			
Taiwan		17		20	44		

Continued.

Table 1. ***Continued.***

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
Thailand	831	32	62		227		14
Turkey				17	24		
USSR	301	213					
Yemen Arab Republic	357	48					
AMERICA							
Argentina	725		2	224			28
Belize	69			361			
Brazil	493	60	40				28
Canada	25			64	10		
Chile				467			2
Colombia	69						
Costa Rica		5					
Ecuador				10			
El Salvador	240						
Guatemala	165						
Honduras	283						
Mexico	1386		16	478			
Nicaragua	69						
Peru				224			
Surinam	146						
Uraguay	246						
USA	5012	218	299	1174	159	10	602
Venezuela	257		12				14
West Indies	2		83		31		4
EUROPE							
Bulgaria				64			
Denmark	120		50	49			
Federal Rep. of Germany	2	3	5	4	13		10
France	15	15	10	48	18		
Greece				224			
Hungary	3	26					
Itaty	331	18	121	15	20		
Rumania	127						
Spain				224			
Switzerland	3	4					
UK	51	21	49	38	78		5
AUSTRALIA							
Australia	4		196	125	57		46
Total	31649	9428	2910	9837	5802	882	911

Import of Plant Material

A total of 3111 seed and plant samples of sorghum, pearl millet, pigeonpea, chickpea, groundnut, minor millets, *Atylosia, Rhynchosia,* and herbarium specimens were received from 25 countries, (Table 2) and released to ICRISAT after thorough examination and treatment as necessary by the National Plant Quarantine Service at the Central Plant Protection Training Institute (CPPTI), Hyderabad, and NBPGR, New Delhi. The imported ground-

Table 2. Plant material imports during 1982.

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
AFRICA							
Botswana	6						
Burundi		2					
Ethiopia				186		6	1
Kenya		15	4				
Malawi			8				
Mali	98	168					
Mozambique						4	
Niger		41					
Nigeria	193	15					
Rwanda			3		2		
Senegal		130					
Sudan	70	376					
Tanzania			52		43	19	2
Upper Volta	29	12					
Zimbabwe		36			113		
ASIA							
Bangladesh				3			
Japan					17	188	
USSR				2			
AMERICA							
Mexico						148	
Surinam					2		
USA	32	280	5		397		1
Venezuela	31						
EUROPE							
Italy	85	105			95	44	
UK					10		
AUSTRALIA							
Australia			14				18
Total	544	1180	86	191	679	409	22

nut seeds were first grown in the net house at CPPTI and only healthy, virus-free plants were released to ICRISAT.

Postentry Quarantine

Plant quarantine regulations of the Government of India require the first generation of all incoming seed and plant samples for ICRISAT to be grown in the Postentry Quarantine Isolation Area (PEQIA). In all, 2665 samples of the five mandate crops were planted in the PEQIA. Throughout the growth period, the plants were closely monitored jointly for exotic diseases by the National Plant Quarantine officials posted at CPPTI and by quarantine staff of ICRISAT. Any suspect plants were rogued and burned. Only seeds from healthy plants were released to ICRISAT scientists.

Meetings

ICRISAT actively participated in "International Consultation on a System for Safe and Efficient Movement of Materials in Global Germplasm Exchange Networks," in cooperation with FAO and IBPGR, held in June 1982 at CIAT, Cali, Colombia, where modalities for safe, smooth, expeditious exchange of germplasm between the International Agricultural Research Centers and different countries were discussed.

Training and Visitors

The Plant Quarantine Unit gave 5 days' training to in-service personnel from Senegal, Gambia and Sudan in August 1982. Practical and theoretical aspects of plant quarantine- were emphasized with special reference to exchange of germplasm.

Statistics Unit

The Unit provided an advisory service to ICRISAT scientists in planning experiments and analyzing of data. Requests for advice averaged more than 50 per month. We frequently visited fields and laboratories for better understanding of research problems and to discuss proposed experiments with scientists.

Discussions with scientists prompted the following studies:

1. A procedure to test the preference of *Trichogramma brasiliensis* for sorghum or pigeonpea leaves using a linear model with a correlated error structure.
2. Developing Genstat Computer procedures to deal with multilocation varietal data.
3. Developing a procedure to use the theory of least squares to estimate components of mean when some generation variances are zero in plant breeding experiments.
4. Developing checkerboard layout to assess the response of sorghum varieties to *Striga* with test varieties on 'white' plots and a susceptible control to monitor *Striga* pressure on the remaining plots.

A member of the Rothamsted statistical unit gave a series of talks on the Genstat computer package.

ICRISAT statisticians gave a series of seminars, participated in scientific meetings, and prepared technical reports for staff members (Technical reports 1-11, 1982).

Computer Services

The Computer Services Unit provides time-sharing 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 computer packages, and conduct seminars on using the computer for daily routines of ICRISAT scientists, administrators, and service departments.

State of Development

Transition from the old computer system (PDP-11/45) to the new VAX-11/780, was nearly completed by January 1982. Almost all major applications previously available are now available in an improved form on the new computer.

The increased capacity and capability of the new system now permit us to support administrative functions. A computerized payroll system has already been developed, tested, and used (November 1982).

A system for managing particulars of conference delegates was developed as an outgrowth of a system to manage details of ICRISAT's Tenth Anniversary. Another administrative system developed permits physical plant managers to track work orders.

Although emphasis has been on administrative applications, we are still developing software to support research. Specialized programs for clustering and diallel analysis were added to our locally developed statistical analysis collection. Also, an on-line system for pedigree management has been developed and is being tested in two plant breeding programs. We are actively encouraging use of word processing software available with the VAX system, and several staff members routinely use word processing to produce reports and papers. Specialized software has been developed locally to enhance the VAX's word processing capability.

Despite the new computer, we were plagued by hardware failures and power problems—the most serious in April when a combination of disk-drive and Uninterruptible Power System failures caused us to lose more than half the available computing time. Visits by computer experts from both the computer company and power company resulted in increased computer-system availability the last quarter of 1982.

The program head attended the National Computer Conference in Houston, Texas, in June 1982; the U.S. Fall DECUS Symposium in Anaheim, California, in December 1982, and a meeting of Computer Center Directors of International Agricultural Research Centers in Cairo in December 1982. Another staff member attended the annual meeting of the Computer Society of India at Madras in January 1982.

Looking Ahead

Adding more terminals in early 1983 will provide computer access to more people. Emphasis in 1983 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; purchase order and inventory control will be computerized; and an interface between the phototypesetting equipment and the computer system will be developed to strengthen and extend our word processing capabilities.

Library and Documentation Services

Acquisition

ICRISAT's Library and Documentation services were consolidated during 1982. Although budgetary constraints held book purchase down during the year, our improved exchange program permitted us to maintain the tempo of acquisitions (Table 3). The library committee reviewed the journals we subscribed to, deleted some, and recommended for some new subscriptions.

Reprography

The reprographic unit was reorganized to operate more efficiently with the available facilities. Efforts are now being made to improve photocopying facilities to cope with increasing demands.

Table 3. Status of acquisitions, ICRISAT Library, 1982.

Documents	Additions during 1982	Total holdings (Dec 1982)
Books and reports	1028	16696
Bound volumes of periodicals	815	10582
Annual reports	171	667
Reprints, photocopies, etc	449	1950

Sorghum and Millets Information Center (SMIC)

SMIC Phase I activity ended in March 1982, and Phase II began 1 April. Most of the objectives of Phase I, except some printing, were reached. In Phase II, the main emphasis has been on computerizing the Information Retrieval (IR) service, compiling annual annotated bibliographies, and preparing status reports.

Computerization. The computerization activity started in October when a terminal was installed and hooked up with the ICRISAT Vax 11/780. Computer programs to produce author and subject indexes have already been written and successfully tested. Work is in progress to produce author and subject indexes of *Sorghum Bibliography* 1977-1980. Design work on a computer based IR system is progressing, and suitable software soon will be developed.

Annotated Annual Bibliographies. Compiling annual annotated bibliographies from 1981 on (part of Phase II) has started. For *Sorghum Bibliography* 1981, nearly 800 references and 450 reprints have been collected; for the *Millets Bibliography* 1981, 450 references and 335 reprints. A newly designed input sheet facilitates transfer of data to the computer.

Status reports. The first status report entitled "Soil *Fertility and Fertilizer Use Research on Sorghum in India—A Review,"* was prepared jointly by an ICRISAT scientist and a scientist from the European Nitrogen Service Program, New Delhi. The Sorghum and Millets Information Center (SMIC) collected nearly 700 references, and supplied photocopies to reviewers. Work also started on *"Agrometeorological Studies on Sorghum and Millets."*

SMIC Services. SMIC supplied 642 reprints on specific requests from scientists, and compiled 27 ad hoc bibliographies on demand. We also published 11 Selective Dissemination of Information (SDI) services, and 3 SMIC Newsletters (in English and French) during the year. The *Directory of Sorghum and Millets Research Workers* was published in May 1982.

Publications

Journal Article

DUTTA, S. 1982. Synopsis journals—the communication media for the transition period. Annals of Library Science and Documentation 29(2): 45-50.

Conference Papers

DUTTA, S. 1982. Information systems and networks with special reference to agricultural information. Presented at the Seminar on Library and Communication, 18-20 Mar 1982, Osmania University, Hyderabad, Andhra Pradesh, India.

DUTTA, S. 1982. SDI service of ICRISAT. Presented at the Workshop on Information Services for Agriculture, 7-8 Aug 1982, Bidhan Chandra Krishi Viswa Vidyalaya, Mohanpur, West Bengal, India.

DUTTA, S. 1982. SMIC: a resume of achievements and aspirations. Presented at the Meeting of Specialized Information Analysis Centres, 4-8 Oct 1982, Montebello, 1DRC, Ottawa, Canada.

DUTTA, S. 1982. Planning for agricultural information system in India. Presented at the XXV1I1 1LA Conference, 20-23 Oct 1982, Lucknow, Uttar Pradesh, India.

GILLIVER, B. 1982. Biometricians' role in agricultural research in the Third World. Presented at the XI International Biometrics Conference, 6-11 September 1982, Toulouse, France.

KUMAR, R.P., and DUTTA, S. 1982. Selective dissemination of information (SDI) service of ICRISAT: an evaluation. Pages 59-65 *in* Information services in India: papers presented at the Tenth National Seminar of IASLIC, 21-24 Dec 1982, IIT, Kanpur, Uttar Pradesh, India (eds. A.K. Roy, and S.K. Kapoor). IASLIC Special Publication No. 22. Calcutta, West Bengal, India: Indian Association of Special Libraries and Information Centres.

SINGH, M. 1982. A robust method of estimating components of means from plant breeding data. In Proceedings, International Conference on Frontiers of Research in Agriculture, 27 September-1 October 1982, Indian Statistical Institute, Calcutta, India.

ICRISAT Governing Board—1982

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ICRISAT Senior Staff-as of Dec 1982

Administration

L. D. Swindale, Director General
J. S. Kanwar, Director of Research (on sabbatic leave from Apr 1982)
R. W. Gibbons, Director of Research (from Apr 1982)
J. C. Davies, Director for International Cooperation (until Aug 1982)
M. G. Wedeman, Principal Administrator
S. S. Dhanoa, Special Assistant to Director General and Principal Government Liaison Officer
B. C. G. Gunasekera, Principal Soil and Water Scientist, International Cooperation
N. Patterson, Special Assistant to Director General for Educational Affairs
V. Balasubramanian, Executive Assistant to Director General
Joyce Gay, Administrative Secretary to Director General
Sunetra Sagar, Administrative Secretary to Director of Research
S. Krishnan, Executive Assistant (International Cooperation)
D. Mitra, Fiscal Manager
A. Banerji, Assistant Manager (Fiscal)
V. S. Swaminathan, Accounts Officer
A. N. Venkatswamy, Accounts Officer
B. K. Johri, Personnel Manager
P. Suryanarayana, Personnel Officer
N. S. L. Kumar, Personnel Officer
R. Vaidyanathan, Purchase and Stores Manager
R. Seshadri, Assistant Manager, Purchase and Stores (until Mar 1982)
K. P. Nair, Purchase Officer
D. K. Mehta, Stores Officer
D. V. Rama Raju, Purchase Officer
K. C. Saxena, Stores Officer
S. K. Dasgupta, Scientific Liaison Officer (Visitors' Services)
A. Lakshminarayana, Scientific Liaison Officer (Visitors' Services)
N. Rajamani, Travel Officer
R. Narsing Reddy, Transport Officer
K. K. Sood, Security Officer
K. K. Vij, Executive Assistant (Liaison), Delhi Office
V. Lakshmanan, Executive Assistant
N. Suryaprakash Rao, Resident Medical Officer
P. Subrahmanyam, Administrative Assistant

International Cooperation

M. Tardieu, Coordinator of Programs, West Africa (from Nov 1982)
K. F. Nwanze, Principal Millet Entomologist and Acting Team Leader, Niger
K. Anand Kumar, Principal Millet Breeder, Niger (from Feb 1982)
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
C. M. Pattanayak, Principal Sorghum Breeder/ Team Leader, Upper Volta (on sabbatic leave until Sept 1982)
A. J. Dagenais, Administrative Officer, Upper Volta
K. V. Ramaiah, *Striga* Physiologist, 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 and Acting Team Leader, Upper Volta
Helga Vierich, Principal Social Anthropologist, Upper Volta
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J. F. Scheuring, Principal Cereals Breeder, Mali
P. G. Serafini, Principal Cereals Agronomist, Mali
S. O. Okiror, Principal Millet Breeder, Team Leader, Nigeria
N. G. P. Rao, Regional Sorghum Breeder, Nigeria
J. H. MacFarlane, Principal Cereals Entomologist, Nigeria
Brhane Gebrekidan, ICRISAT/SAFGRAD Coordinator for Sorghum and Millet, Eastern and Southern Africa, Kenya (from Sept 1982)
R. P. Jain, Principal Millet Breeder, Sudan
Gebisa Ejeta, Principal Sorghum Breeder, Sudan
S. N. Nigam, Principal Groundnut Breeder, Malawi (from Aug 1982)
V. Y. Guiragossian, Principal Sorghum Breeder, Mexico
C. Paul, Principal Sorghum Agronomist, Mexico (from Sept 1982)
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
T. Omori, Principal Sorghum Breeder, Visiting Scientist
Bhola Nath Verma, Plant Breeder
D. S. Murty, Plant Breeder
B. L. Agrawal, Plant Breeder
B. V. S. Reddy, Plant Breeder
M. J. Vasudeva Rao, Plant Breeder
N. Seetharama, Plant Physiologist
R. K. Maiti, Plant Physiologist
Suresh Pande, Plant Pathologist
R. Bandopadhyay, Plant Pathologist
S. L. Taneja, Entomologist
H. C. Sharma, Entomologist
S. P. Jaya Kumar, Administrative Assistant

Pearl Millet

D. J. Andrews, Principal Plant Breeder and Leader
L. A. Hunt, Principal Plant Breeder (from Sept 1982)
F. R. Bidinger, Principal Plant Physiologist
R. J. Williams, Principal Plant Pathologist
P. J. Dart, Principal Cereal Microbiologist
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
D. B. Godse, Microbiologist (until Feb 1982)
K. R. Krishna, Microbiologist
Nirmala Kumar, Administrative Secretary

Pulses

Y. L. Nene, Principal Plant Pathologist and Leader (on sabbatic leave from Apr 1982)
D. G. Faris, Principal Plant Breeder, Pigeonpea and Leader (Apr-Oct 1982)
W. Reed, Principal Entomologist and Leader (from Oct 1982)
J. B. Smithson, Principal Plant Breeder, Chickpea
J. A. Thompson, Principal Pulse Microbiologist
D. Sharma, Senior Plant Breeder, Pigeonpea
K. C. Jain, Plant Breeder, Pigeonpea
K. B. Saxena, Plant Breeder, Pigeonpea
L. J. Reddy, Plant Breeder, Pigeonpea (until Oct 1982)
S. C. Gupta, Plant Breeder, Pigeonpea
G. K. Bhatia, Plant Breeder, Pigeonpea (until May 1982)
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
C. S. Pawar, Entomologist
S. P. S. Beniwal, Senior Plant Pathologist
M. P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist
O. P. Rupela, Microbiologist
J. V. D. K. Kumar Rao, Microbiologist
D. M. Pawar, Senior Supervisor
M. D. Gupta, Senior Research Technician/ Senior Supervisor

Groundnut

R. W. Gibbons, Principal Plant Breeder and Leader (until May 1982)
D. McDonald, Principal Plant Pathologist and Leader (from May 1982)
D. V. R. Reddy, Principal Plant Virologist
J. H. Williams, Principal Plant Physiologist
J. P. Moss, Principal Cytogeneticist
K. Tanaka, Principal Plant Pathologist, Visiting Scientist
A. M. Ghanekar, Plant Virologist
L. J. Reddy, Plant Breeder (from Nov 1982)
P. Subrahmanyam, Plant Pathologist
V. K. Mehan, Plant Pathologist
P. T. C. Nambiar, Microbiologist
P. W. Amin, Entomologist
A. K. Singh, Cytogeneticist
D. C. Sastry, Cytogeneticist
S. L. Dwivedi, Plant Breeder
S. N. Nigam, Plant Breeder (until Aug 1982)
R. C. Nageswar Rao, Plant Physiologist

A. B. Mohammed, Entomologist
Mohinder Pal, Plant Physiologist
Y. Bhaskar, Assistant Engineer

Farming Systems

S. M. Virmani, Principal Agroclimatologist and Leader
R. W. Willey, Principal Agronomist (on Sabbatic leave from Mar 1982)
J. T. Moraghan, Principal Soil Scientist (until Mar 1982)
C. W. Hong, Principal Soil Scientist (from May 1982)
S. A. El-Swaify, Principal Soil Scientist (from July 1982)
G. E. Thierstein, Principal Agricultural Engineer
J. R. Burford, Principal Soil Chemist
S. M. Miranda, Principal Soil and Water Engineer
M. V. K. Sivakumar, Principal Agroclimatologist
Y. Nishimura, Principal Assistant Agronomist
R. Busch, Principal Soil Scientist
M. Wurzer, Principal Assistant Soil Scientist
S. V. R. Shetty, Agronomist
Piara Singh, Soil Scientist
Sardar Singh, Soil Scientist
T. J. Rego, Soil Scientist
K. L. Sahrawat, Soil Chemist
A. K. S. Huda, Agroclimatologist
M. R. Rao, Agronomist
M. S. Reddy, Agronomist
M. Natarajan, Agronomist
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P. Pathak, Agricultural Engineer
P. N. Sharma, Agricultural Engineer (until Apr 1982)
K. L. Srivastava, Agricultural Engineer
R. K. Bansal, Agricultural Engineer
J. Han Krishna, Agricultural Engineer (until Feb 1982)
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Siloo Nakra, Executive Assistant
Surendra Mohan, Administrative Assistant

Economics

J. G. Ryan, Principal Economist and Leader (until Mar 1982)
M. von Oppen, Principal Economist and Leader (from Mar 1982)
V. S. Doherty, Principal Social Anthropologist (until Nov 1982)
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N. S. Jodha, Senior Economist
R. D. Ghodake, Economist
R. P. Singh, Economist
K. N. Murthy, Economist
K. G. Kshirsagar, Senior Research Technician
R. S. Aiyer, Administrative Assistant

Support Programs

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Umaid Singh, Biochemist
V. Subramanian, Biochemist

Genetic Resources

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K. E. Prasada Rao, Botanist
S. Appa Rao, Botanist
R. P. S. Pundir, Botanist
P. Remanandan, Botanist
V. Ramanatha Rao, Botanist

Plant Quarantine

B. K. Varma, Plant Quarantine Officer (from Jun 1982)
Upendra Ravi, Senior Technician

Fellowships and Training

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A. S. Murthy, Senior Training Officer
B. Diwakar, Training Officer
T. Nagur, Training Officer
A. Prakash Rao, Training Officer (from Mar 1982)

Information Services

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S. Varma, Editor/Writer
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G. K. Guglani, Senior Artist
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Murari Singh, Statistician (from Mar 1982)

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Library and Documentation Services

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A. G. Fagot, Manager
S. Mazumdar, Assistant Manager (Food Services)
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M. C. Ranganatha Rao, Assistant Engineer
K. Santhanam, Executive Assistant

Acronyms and Abbreviations Used in this Annual Report

Acronyms

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
AGRHYMET	Center for Applied Research and Training in Agrometeorology and Hydrology (Niger)
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)
ARC	Agricultural Research Corporation (Sudan)
ART	Arhar Regional Trial
CATIE	Centra Agronomico Tropical de Investigacion y Ensenanza (Costa Rica)
CENARGEN	Centra Nacional de Recursos Geneticos (Brazil)
CFTRI	Central Food Technological Research Institute (India)
CGIAR	Consultative Group on International Agricultural Research
CIABN	Chickpea International Ascochyta Blight Nurseries
CIAT	Centra Internacional de Agriculture Tropical (Columbia)
CIMMYT	Centra Internacional de Mejoramiento de Maiz y Trigo (Mexico)
CIVT	Cowpea International Variety Trial
CLAIS	Comision Latinoamericana de Investigadores en Sorgo (Guatemala)
CPPTI	Central Plant Protection Training Institute (India)
CTSAN	Cold Tolerant Sorghum Adaptation Nursery
DEC	Digital Equipment Corporation
DECUS	Digital Equipment Corporation Users' Society
DONHIAH	Disease Observation Nursery for Improvement of Advanced Hybrids
EACT	Extra-early maturity Arhar Coordinated Trial
ELISA	Enzyme-linked Immunosorbent Assay
ELVT	Elite Varieties Test
EMBRAPA	Empresa Brasiliera de Pesquisa Agropecuaria (Brazil)
EPAY	Early-maturing Pigeonpea Adaptation Yield Trial
	Ethiopia Sorghum Improvement Program
ESVYT	Elite Sorghum Varieties Yield Trial-
EVT	Experimental Varietal Trial
EXACT	Extra-extra-early Arhar Coordinated Trial
F_2MLT-DL	F_2 Multilocation Trial-Desi, Long duration
F_2MLT-DS	F_2 Multilocation Trial-Desi, Short duration
F_2MLT-DL	F_3 Multilocation Trial-Desi, Long duration
F_3MLT-DS	F_3 Multilocation Trial-Desi, Short duration
FAO	Food and Agriculture Organization of the United Nations
FSRP	Farming Systems Research Program
GENSTAT	General Statistical Package (UK)

GRU	Genetic Resources Unit
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit (West Germany)
HAU	Haryana Agricultural University (India)
IARC	International Agriculture Research Centres (Australia)
IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources (Italy)
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas (Syria)
ICAT	International Chickpea Adaptation Trial
ICGS	ICRISAT Groundnut Synthetic
ICMH	ICRISAT Millet Hybrid
ICMPE	ICRISAT Millet Pathology Ergot
ICMS	ICRISAT Millet Synthetic
ICMV	ICRISAT Millet Variety
ICRRWN	International Chickpea Root Rots and Wilt Nursery
IDMRS	ICRISAT Data Management and Retrieval System
IDRC	International Development Research Centre (Canada)
IFDC	International Fertilizer Development Center (USA)
IGN	Institut Geographique National (Senegal)
IIASA	International Institute of Applied Systems Analysis (Austria)
IITA	International Institute of Tropical Agriculture (Nigeria)
HUTPSMR	ICAR-ICRISAT Uniform Trial for Pigeonpea Sterility Mosaic Resistance
HUTPWR	ICAR-ICRISAT Uniform Trial for Pigeonpea Wilt Resistance
ILCA	International Livestock Center for Africa (Ethiopia)
INIA	Institute Nacional de Investigaciones Agricoles (Mexico)
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet
IPMAN	International Pearl Millet Adaptation Nursery
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 Vivrieres (France)
IRRI	International Rice Research Institute (Philippines)
ISAT	Irrigated Semi-Arid Tropics
ISDMN	International Sorghum Downy Mildew Nursery
ISHAT	International Sorghum Hybrid Adaptation Trial
ISLDN	International Sorghum Leaf Disease Nursery
ISMN	International Sorghum Midge Nursery
ISPYT	International Sorghum Preliminary Yield Trial
ISRA	Institut Senegalais de Recherche Agricole (Senegal)
ISSFN	International Sorghum Shoot Fly Nursery
ISSGQ	International Symposium on Sorghum Grain Quality
ISVAT	International Sorghum Variety Adaptation Trial
IYET	Initial Yield Evaluation Trial
LASDTYT	Latin American Sorghum Drought Tolerant Yield Trial
LASEVYT	Latin American Sorghum Elite Variety Yield Trial
LASON	Latin American Sorghum Observation Nursery

LPAY	Late-maturity Pigeonpea Adaptation Yield Trial
MPAY	Medium-maturity Pigeonpea Adaptation Yield Trial
NARC	National Agricultural Research Centre (Pakistan)
NBPGR	National Bureau of Plant Genetic Resources (India)
NBSS & LUP	National Bureau of Soil Survey and Land Use Planning
NIN	National Institute of Nutrition (India)
NSAT	Nonirrigated Semi-Arid Tropics
NVRS	National Vegetable Research Station (UK)
OAU	Organization for African Unity
ODA	Overseas Development Administration (UK.)
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer (France)
PAU	Punjab Agricultural University (India)
PEQIA	Postentry Quarantine Isolation Area
PMART	Pearl Millet African Regional Trial
PMIST	Pearl Millet Initial Synthetics Trial
PMXN	Pearl Millet Exchange Nursery
PON	Pigeonpea Observation Nursery
PSSFN	Preliminary Sorghum Shoot Fly Nursery
PTPMT	Plant Type Multilocation Trial
PVT	Preliminary Variety Trial
SADCC	Southern African Development Coordinated Conference
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	Semi-Arid Tropics
SEPON	Sorghum Elite Progeny Observation Nursery
SMIC	Sorghum and Millets Information Center (India)
SMIN	Source Material Inbred Nursery
SORGF	Sorghum Simulation Model
SSVPYT	Selected Sorghum Varieties Preliminary Yield Trial
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNU	United Nations University (Japan)
UPN	Uniform Progeny Nursery
USAID	United States Agency for International Development
VMS	Virtual Memory System
WADREVT	West African Disease Resistant Elite Varietal Trial
WAMDT	West African Mildew Differential:Trial
WARDEN	West African Regional Disease Evaluation Nursery
WMO	World Meteorological Organization of the United Nations
WSARP	West Sudan Agricultural Research Program

Abbreviations

ATR	Animal traction
BBF	Broadbed and furrow
BHC	Benzene hexachloride
BYMV	Bean Yellow Mosaic Virus
CD	Critical Difference
CDA	Controlled droplet applicator
CGR	Crop growth rate
CMMV	Cowpea Mild Mottle Virus
CMV	Cucumber Mosaic Virus
CV	Coefficient of variation
cv	Cultivar
DAE	Days after emergence
DAP	Days after planting
DAS	Days after sowing
DAYEM	Day length at emergence
DM	Downy mildew
DSCO	Drought stress coefficients
EMS	Ethyl methane sulfonate
FI	Fodder incorporated
FYM	Farmyard manure
GCA	General combining ability
GDD	Growing degree days
GS	Growth stage
HF	High fertility
IAA	Indole acetic acid
IR	Information retrieval
ISEM	Immunosorbent electron microscopy
ITCZ	Intertropical convergence zone
IVC	Inter-varietal composite
IVP	Intervariety population
LAI	Leaf area index
LER	Land equivalent ratio
LF	Low fertility
LSD	Least significant difference
LVP	Low-viability pollen
MAI	Moisture availability index
MC	Medium composite
NEC	New early composite
PCV	Peanut Clump Virus
PDM	Pod dry matter
PF	Partitioning factor
PGR	Pod growth rate
PI	Panicle initiation
PMV	Peanut Mottle Virus
PPFD	Photosynthetic photon flux density
PVA	Polyvinyl alcohol
RMSE	Root mean square error
SCA	Specific combining ability
SDD	Stress degree days
SD1	Selective disseminatin of information
SDM	Sorghum downy mildew
SE	Standard error
SMD	Sterility mosaic disease
SRC	Smut-resistant composite
SSC	Super serere composite
SSP	Simple superphosphate
TDM	Total dry matter
TMV	Tomato Mottle Virus
TSWV	Tomato Spotted Wilt Virus
VAM	Vesicular arbuscular mychorrhiza
VLS	Village-Level Study
VP	Viable pollen
WAE	West African early
WC	World composite

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