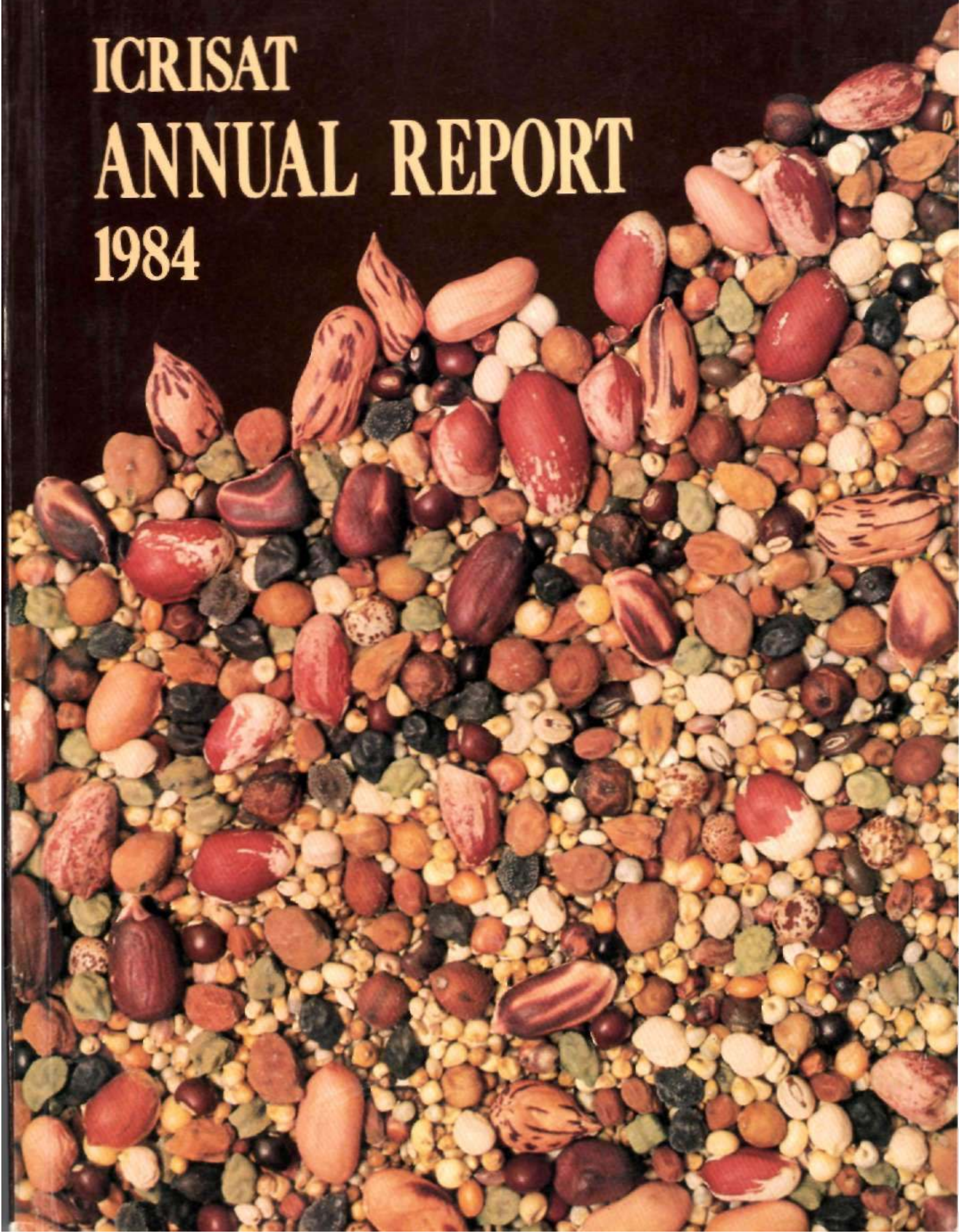
ICRISAT
ANNUAL REPORT
1984



Cover: Seeds of ICRISAT mandate crops showing the wide range of diversity in germplasm accessions assembled in our *gene* bank.

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

1985

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

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ICRISAT's Objectives

ICRISAT's mandate is to:

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

About This Report

This Annual Report covers the 1984 calendar year. It 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 nine countries of Africa, Mexico, Syria, and Pakistan where ICRISAT scientists are posted.

The crop improvement programs are presented as interdisciplinary reports on problem areas to better reflect the interactive nature of our scientists' work. Research done by our scientists and cooperative programs outside India is reported with the relevant crop or discipline. Detailed reporting of the extensive activities of ICRISAT's many research support units is beyond the scope of this volume, but a comprehensive coverage of ICRISAT's core research programs is included. More details of the work reported here are given in individual program publications, available from the research program concerned. Offprints of individual sections of this Annual Report also are available from the programs.

ICRISAT now uses SI units in its publications. The SI (Systeme International d'Unites) provides an internationally accepted and reliable way of expressing quantities that is clear and precise. Throughout this Report, the variability of estimates is shown by including standard error (SE); on graphs representing the mean of several observations, the standard error is shown by a bar (I). In discussing levels of probability in the text, significance is generally mentioned at the 5% level; where the level differs, it is indicated parenthetically. Levels of probability are shown in tables by asterisks: * for $P < 0.05$, ** for $P < 0.01$, and *** $P < 0.001$. Unless otherwise specified, available phosphorus (P), refers to the amount of phosphorus extracted from soil by Olsen's method, using 0.5 molar $NaHCO_3$ as the extractant.

This year, for the first time, we are listing ICRISAT plant materials named by the Institute Plant Material Release Committee. Named material appears in the text by its new name followed by its original name in parentheses at the first mention. A full listing appears on pages xxiii and xxiv.

Contents

ICRISAT's Five Crops

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

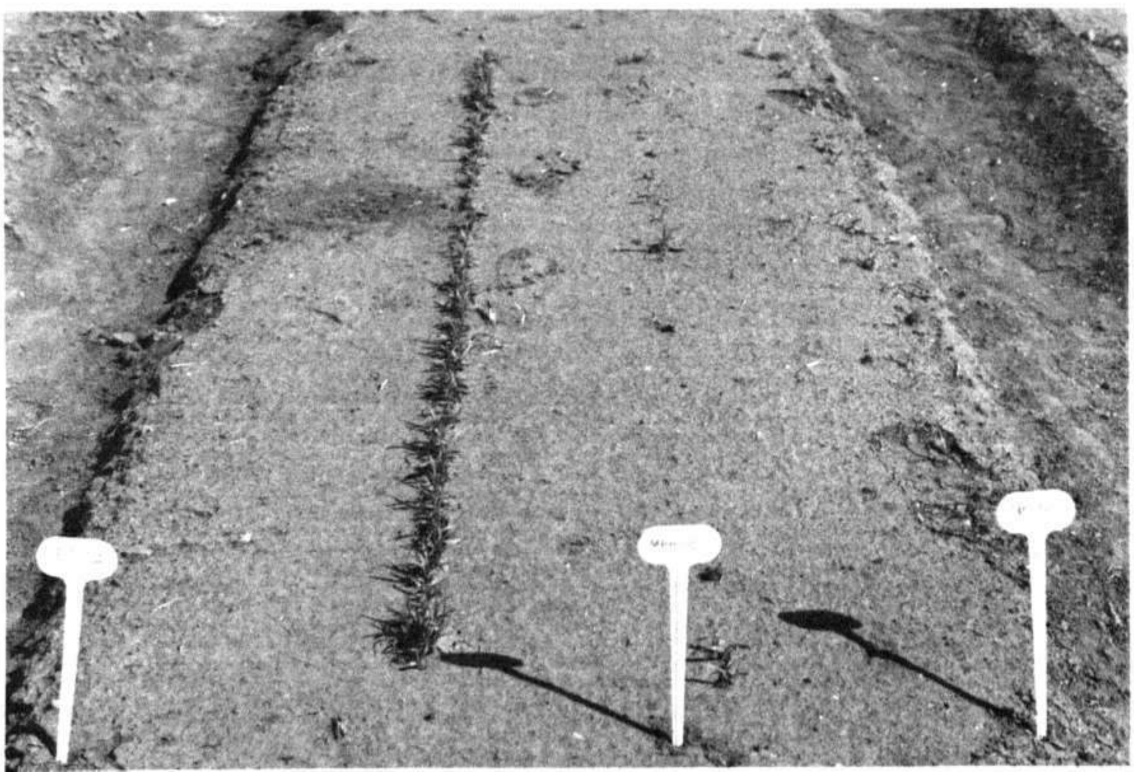
Introduction

ICRISAT made further progress this year in understanding the mechanisms of drought—and how to lessen its devastating effects—as well as in developing plant lines resistant to those other banes of farmers: diseases, insects, and weeds. Solving these problems holds the key to increasing food production throughout the semi-arid tropics (SAT). The best high-yielding varieties and hybrids will mean little to resource-poor farmers of the SAT if they can't withstand and overcome the environmental and biological stresses common to the region.

At ICRISAT Center, in India, we have developed several techniques that are sufficiently well-proven to be used by ICRISAT scientists working in Africa and elsewhere to test material under their environmental conditions. The work on seedling emergence through soil crusts — vital to finding material suited to the harsh conditions in Sahelian Africa, where early establishment can be a salvation — led to the development of a technique that was used this year to evaluate pearl millet from six Sahelian countries and from two countries in southern Africa. We also used a technique developed at ICRISAT Center to screen for emergence in high soil surface temperatures and found some breeding lines that had a tolerance equal to that of one of the best local cultivars in West Africa. These findings will lead to further improvements in the food crops grown there.

While ICRISAT Center remains the focal point for basic research in the battle against drought, the Sahel of Africa is the front line. Good results were reported this year from the ICRISAT Sahelian Center (ISC) near Niamey, Niger, where research has been under way for only 3 years. In a year of record low rainfall at Niamey — 250 mm compared with a normal 570 mm — careful agronomic management yielded good results with millet and cowpea. Grain yields at the Sahelian Center averaged four to five times as much as on local farms.

Poor crop establishment is a major problem in the hot, sandy soils of the Sahel (above). ICRISAT scientists are developing techniques (below), to identify lines that can survive crusted soils and grow under such conditions.



In the Sudan, where drought was especially severe this year, an ICRISAT-developed sorghum hybrid and a pearl millet variety did remarkably well. The Government expects to distribute several thousand tonnes of seed of the high-yielding sorghum hybrid, Hageen Durra 1, to farmers for planting next year. ICRISAT's pearl millet, Ugandi, escaped drought effects due to its earliness and has also attracted the attention of Sudanese farmers.

Diseases are a major constraint to crop production. The typical farmer in the SAT has very limited means to counter them. As reported over the last 2 years, ICRISAT now has lines with multiple resistances in all its crops. During 1984, for example, our Plant Material Release Committee named four pearl millet lines with stable and combined resistance to three major diseases—ergot, smut, and downy mildew—as an aid to breeders in national programs.

Investigations of multiple-disease resistance in pigeonpea led this year to identifying some lines with combined resistance to as many as four diseases. In similar work with chickpea, combined resistance to wilt—a major disease—and two different root rots was identified. Breeding stocks of sorghum now available from ICRISAT carry high levels of resistance to midge and downy mildew.

ICRISAT-developed sorghum hybrid Hageen Durra 1 performed well in the 1984 Sudan drought. Its seed is being multiplied for increased planting.

Groundnut line at right resists foliar diseases, while that at left is susceptible. Progress has been made in incorporating multiple resistances in all ICRISAT crops.

Several ICRISAT lines identified earlier for disease resistance moved ahead in testing by national programs. Two rust-resistant groundnut lines were promoted to an advanced stage in multilocational tests of the Indian national program. Another ICRISAT groundnut gave the top yield—averaged over eight locations—in disease-resistance trials of the Indian program, while eight new lines were entered for similar trials.

Along with drought and diseases, insect and weed pests are major yield reducers in food crops. Because chemical control is beyond the reach of many farmers, ICRISAT's initial work in combating them focused on breeding for natural resistance. But the emphasis has now shifted to integrated pest management, with due attention to pest surveys, monitoring of populations, biological control through parasite and predator studies, and improved agronomic practices, including methods of applying pesticides. Important progress was made on all these fronts during 1984.

ICRISAT's Genetic Resources Unit added 4975 new accessions of our mandate crops, and 408 of minor millets, to our gene bank this year, bringing the total accessions to more than 80 000.

Collecting, conserving, and distributing such accessions is crucial if crop improvement work is to have an impact in different parts of the world. Samples are available on request to scientists throughout the world. We also distribute our material as nurseries for national, regional, and international trials designed to screen specific traits under local conditions.

A key provision of our mandate calls on us not only to develop new technology for increased agricultural production, but also to assist in its transfer to national programs for eventual use by farmers of the SAT. We do this primarily through an intensive training program for young agriculturists, a series of regional and international workshops every year to discuss with scientists the latest findings of our research, and through visits to ICRISAT operations by interested scientists, policymakers, and farmers.

Former trainees from Mali—-now working with their national program and ICRISAT staff in Mali-inspect an improved sorghum variety.

Field technicians emasculating sorghum in Zimbabwe, the base for ICRISAT's cereals improvement project for southern Africa.

More than 900 persons from 69 countries have completed training at ICR1-SAT Center since 1974, and many of them now serve as research leaders, farm managers, field technicians, and extension agents in national and international programs of agricultural improvement. During 1984, 148 scientists, research technicians, and extension personnel from 39 countries participated in training programs at ICRISAT Center; another 27 students or trainees from nine countries worked with our scientists in Burkina Faso, Mali, Mexico, and Niger.

In addition, 217 scientists, extension personnel, bank agricultural officers, and development officers or policymakers from four states of India were provided short-term training at ICRISAT Center. Their training focused on identifying suitable cropping systems for use on broadbeds and furrows, and other factors associated with ICRISAT's technology for deep black soils being tested in the four Indian states of Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra.

Of the 20 workshops held by ICRISAT in 1984, there was at least one in each of the major regional centers where ICRISAT staff are working. They included regional workshops on sorghum research and improvement in West Africa at Ougadougou, on pearl millet improvement in West Africa at the ISC, on groundnut improvement at Lilongwe, Malawi, and on sorghum and millet improvement in southern Africa at Bulawayo, Zimbabwe. These afforded opportunities for scientists working in national programs, and regional and international organizations in these areas, to visit ICRISAT research bases, exchange ideas, and influence ICRISAT plans for future research.

International workshops sponsored or cosponsored by ICRISAT this year included one on sorghum insects, at Texas A & M University in July, and one on rust disease of groundnut at ICRISAT Center in late September.

During the year we had over 8000 visitors, including 2300 farmers from three states of India, 900 of whom attended the 5th annual Farmers' Day at ICRISAT Center in October. Among other visitors were more than 2000 students,

Research directors from Togo, Burkina Faso, Mali, and Senegal evince interest in laboratory work on *Striga* during a visit to ICRISAT Center.

External Program Review team visiting a greenhouse experiment at ICRISAT Center. The panel broadly commended our work.

400 national scientists, and 200 scientists from overseas. Directors of Research from seven West African countries came to see our work and that of Indian national programs, and discuss with us research plans that could vitally affect their countries.

Also among important visitors to our work, both in Africa and India, were two panels of international experts selected by our parent organization — the Consultative Group on International Agricultural Research — to evaluate ICRISAT's research programs and management structure and report to our donors. We were highly pleased that both panels confirmed we are on the right track in pursuit of our goal to bring a better quality of life to the poorest farmers of the SAT and to the villagers dependent on them for their food.

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 contribution from ICRISAT scientists posted at cooperative stations in India, in nine African countries, and in Mexico, Syria, and Pakistan. As background to our research reports, this section presents a brief description of the environments where most of our research is conducted and includes rainfall and temperature data for most of those locations.

ICRISAT Center

The Institute is located at 18°N, 78°E near Patancheru village, Andhra Pradesh, 26 km northwest of Hyderabad. The experimental farm, extending over 1394 hectares, includes two major soil types found in the semi-arid tropics: Alfisols (red soils), which are light and drought-prone, and Vertisols (black soils), which have a high water-holding capacity. The availability of both soil types provides an opportunity to conduct experimental work on our five mandate crops under conditions representative of many SAT areas.

Seasons. Three distinct seasons characterize much of India. In the Hyderabad area the rainy season, also known as the monsoon or kharif, usually begins in June and extends into September. More than 80% of the 800-mm average annual rainfall occurs during those 4 months, in which rainfed crops are raised. The post rainy winter season (October through January), also known as the 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 lasts from February until rains begin again in June, and any crop grown in that season requires irrigation.

Crops. The five ICRISAT crops have different environmental requirements that determine where and when they are grown. In the Hyderabad area, millet and groundnut are sown on Alfisols during June and July, the beginning of the rainy season; at ICRISAT Center, additional generations are 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 short-duration pigeonpeas in December. As in normal farming practice, two crops a year of sorghum can be grown at the Center, one during the rainy season and the other on Vertisols in the postrainy season. Chickpea, a single-season crop, is grown during the postrainy season on residual moisture on Vertisols. At ICRISAT, as in normal farming practice, crops are often grown in various combinations and sequences, which we are working to improve.

Other Research Locations

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. These stations are at Bhavanisagar (11°N), where we screen sorghum for diseases and pests and test pearl millet at a daylength analog similar to the Southern Sahelian Zone of Africa; Anantapur (15°N), a drought-prone area where we screen pearl millet, sorghum, and groundnut under dry conditions in the rainy season; Dharwad (15° N), an especially good site for pest and disease screening, e.g., screening sorghum for downy mildew; Gwalior (26° N), in an area where most of India's long-duration pigeonpea crop is grown; and Hisar (29°N), where chickpea and pearl millet are tested under climatic conditions in which they are mostly grown, and short-duration pigeonpeas are tested in a region where they are increasingly being grown in rotation with wheat.

Our research in Africa is carried out at the

ICRISAT Sahelian Center, near Niamey, Niger (13° N, 2°E, 585 mm rainfall)—which is being developed as our principal base for millet and groundnut research in West Africa, and farming systems associated with those crops—and at national research stations in these other African countries:

Burkina Faso—Kamboinse (12° N, 2° W, 827 mm rainfall), where the principal work is on sorghum—with particular emphasis on *Striga* resistance—millet, and village-level socioeconomic studies.

Mali—Cinzana (13° N, 6°W, 682 mm rainfall), where we are researching sorghum, millet, and agronomic practices associated with these crops.

Nigeria—Samaru (11° N, 8° E, 1133 mm rainfall), where our breeder posted at the Institute of Agricultural Research works on millet.

Senegal—Bambey (15° N, 16° W, 634 mm rainfall), where the emphasis is on developing improved millets.

Kenya—Nairobi (1° S, 37° E, 1066 mm rainfall), the center of an ICRISAT regional network testing sorghum and millet in four major agroecological zones: high, intermediate and low elevations, and very dry lowlands.

Sudan—Wad Medani (14° N, 33° E, 373 mm rainfall), where the major emphasis has been on developing sorghums that can withstand drought, and El Obeid (13° N, 30° E, 418 mm rainfall), where our millet research is being carried out.

Malawi—Chitedze (14° S, 34° E, 880 mm rainfall), where our regional groundnut improvement program for southern and eastern Africa is based. Chitedze, located on the Lilongwe plain, has a tropical continental climate with one rainy season from November to April

Zimbabwe—Bul'awayo (20° S, 29° E, 588 mm rainfall), where our cereals improvement program for the nine African countries of the SADCC region is based at Matopos Research Station. This will be one of ICRISATs major research projects in Africa.

ICRISAT also has scientists posted in these other countries:

Syria—Aleppo/Tel Hadya (36° N, 37° E, 340 mm rainfall), where our staff work with ICARDA on kabuli-type chickpeas for spring or winter sowing in the Mediterranean region, and South and Central America.

Pakistan—Islamabad (34° N, 73° E, 960 mm rainfall), where the emphasis is research on developing chickpeas resistant to Ascochyta blight.

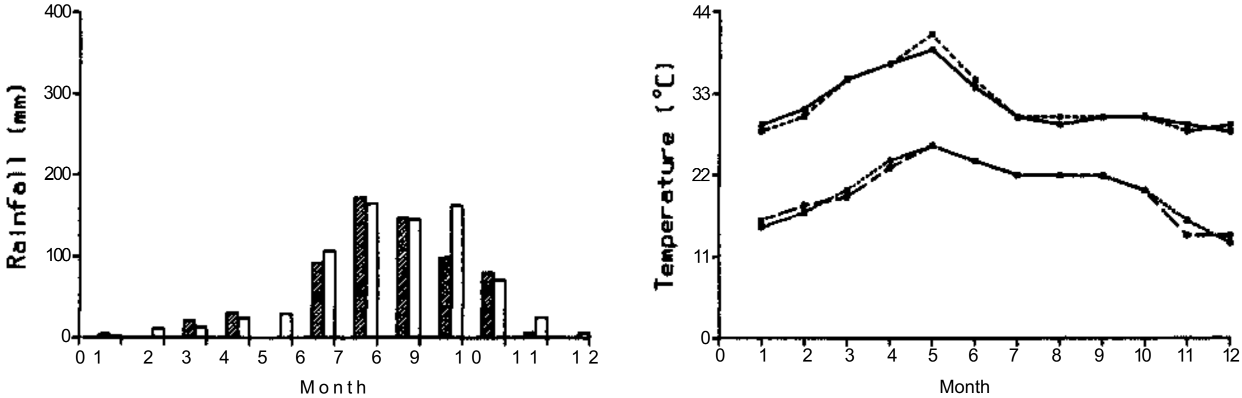
Mexico—Our breeder and agronomist based at CIMMYT, El Batan (19° N, 99° W, 750 mm rainfall), work on high-altitude, cold-tolerant sorghums and material adapted for low and intermediate elevations in Latin America and the Caribbean.

The Weather

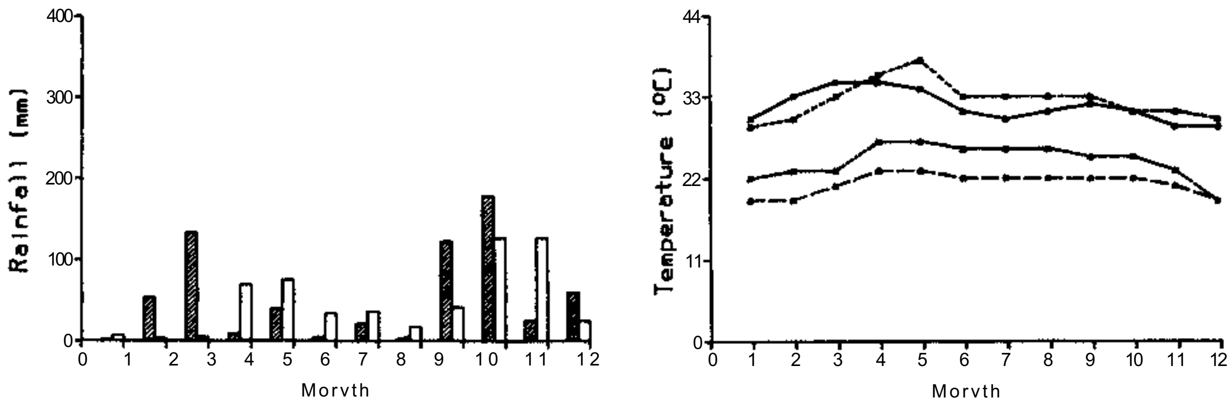
In the following figures we present rainfall and temperature data for the main locations of our research.

1984 rainfall   Normal rainfall

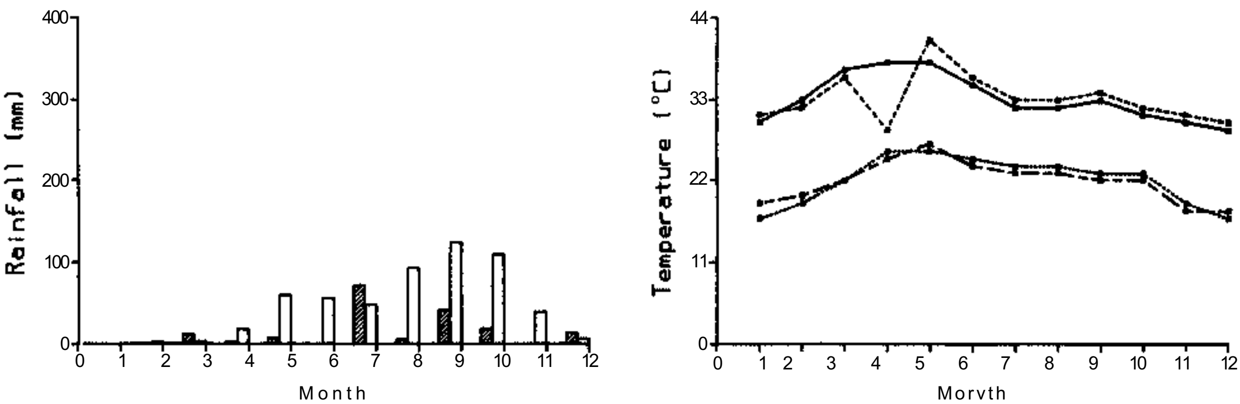
1984 max temp
Normal max temp
1984 min temp
Normal min temp



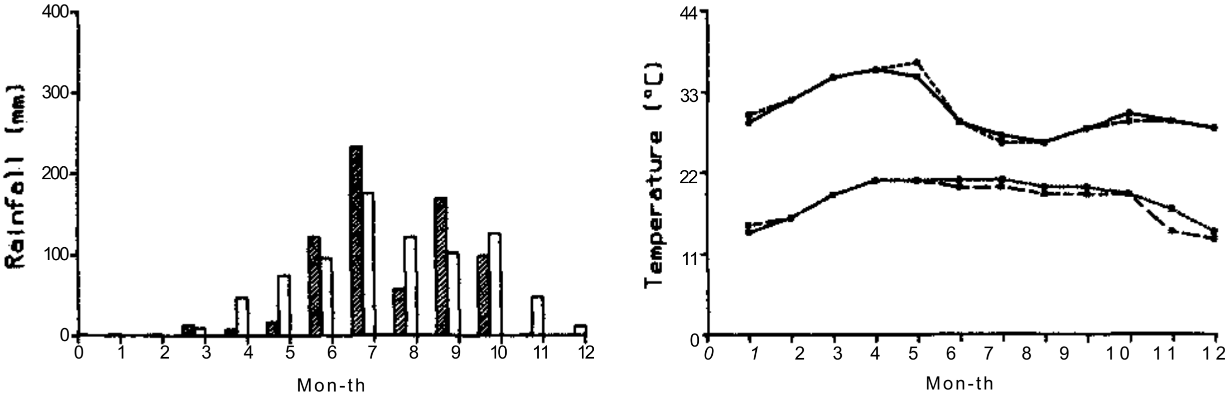
ICRISAT Center. The annual rainfall in 1984 was 655 mm, 14% less than the normal 764 mm. The rainy season total (June to October) was 591 mm against the normal 653 mm. Rainfall during September was 39% less than normal. The average daily maximum temperature in May was 2°C higher than normal, as it was at all our Indian cooperative research stations.



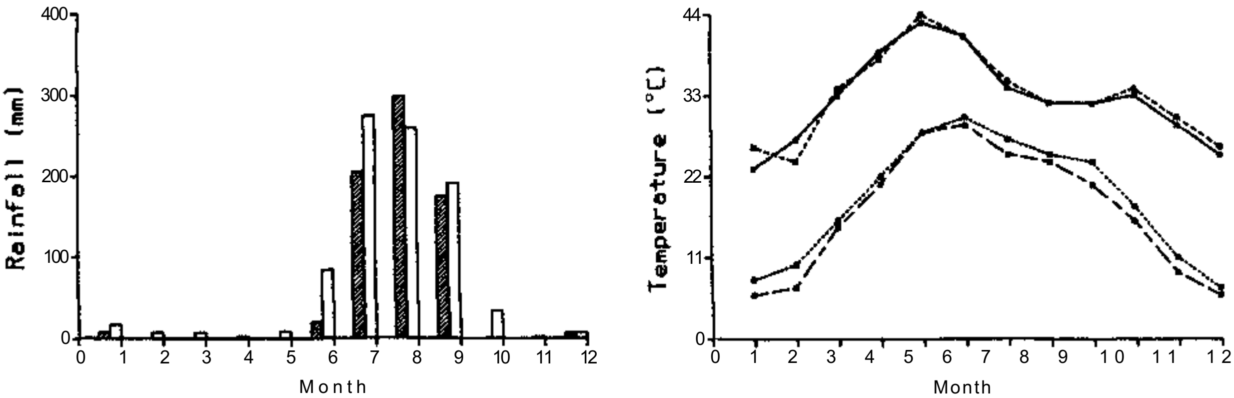
Bhavanisagar. Rainfall received in 1984 was 657 mm, i.e., 9% below normal. Sixty-six percent of the annual rainfall fell during March, September, and October.



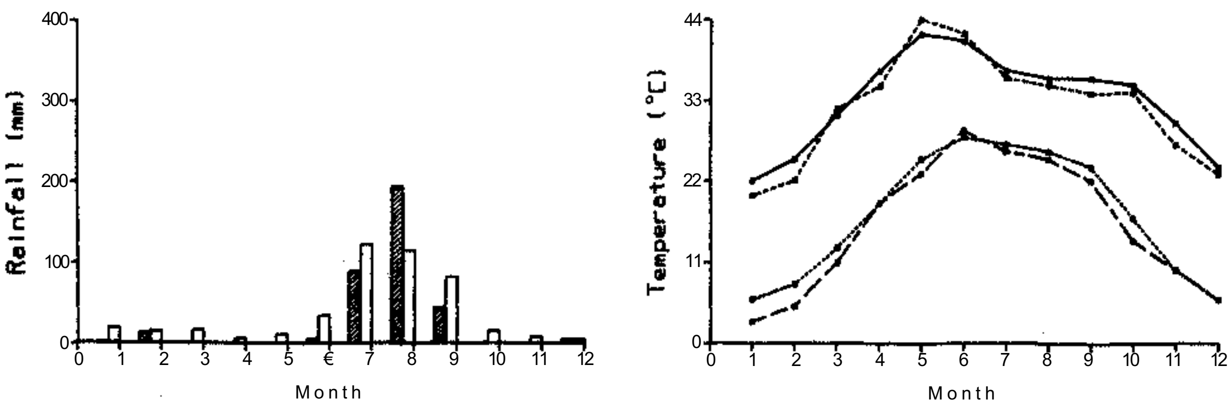
Anantapur. Rainfall in 1984 was 176 mm, 69% below normal Of 563 mm normal annual rainfall, 42% is usually received in September and October. This year rainfall in these two months was only 59 mm.



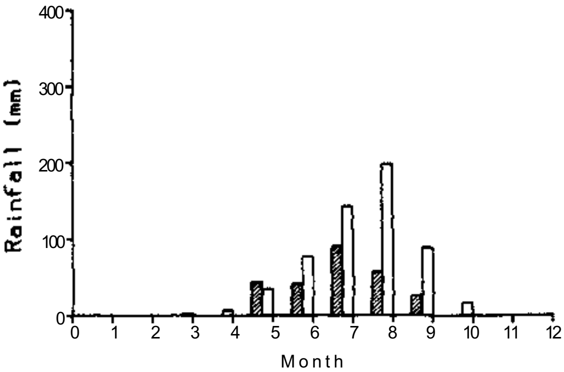
Dharwad. The annual rainfall in 1984 was 725 mm, 11% below the normal 818 mm. However, rainfall from May to October 1984 was normal (700 mm).

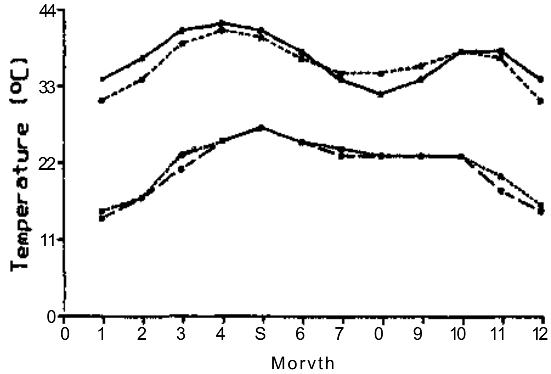


Gwalior. Rainfall received during the 1984 rainy season (June to October) was 701 mm, 17% below the normal 843 mm.

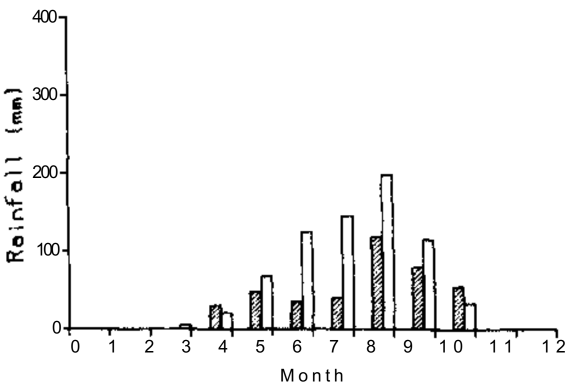


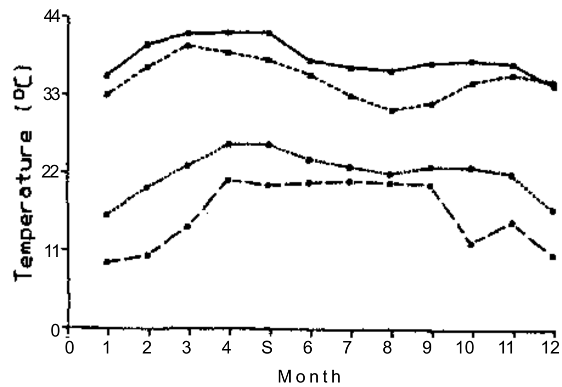
Hisar. The total annual rainfall, 351 mm, was 21% below the normal 447 mm. From June tc September 331 mm rain fell, less than the normal 351 mm.



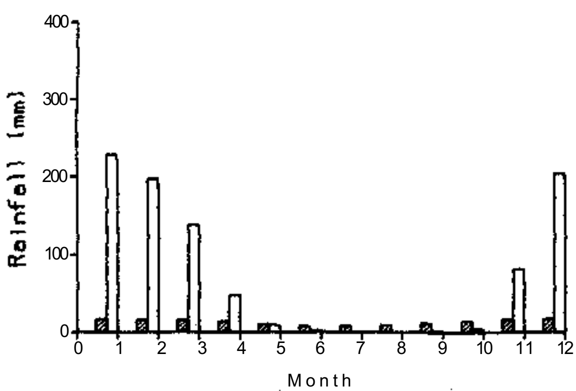


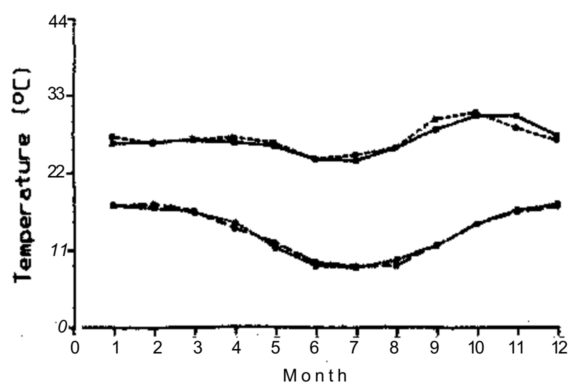
ICRISAT Sahelian Center. Rainfall received from June to October was only 216 *mm,* 63% less than the normal 588 mm. Total annual rainfall was only 59% below the normal 638 mm. The average daily maximum temperatures were lower than normal, except in July, August, and September.



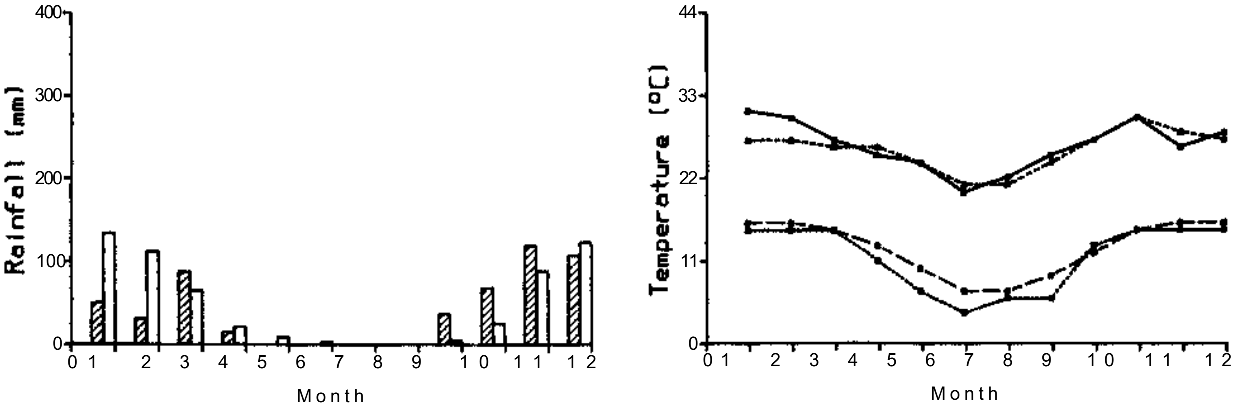


Kamboinse. Rainfall during the 1984 season was less than 50% of the long-term average at Kamboinse. Temperatures were lower than in a normal year.

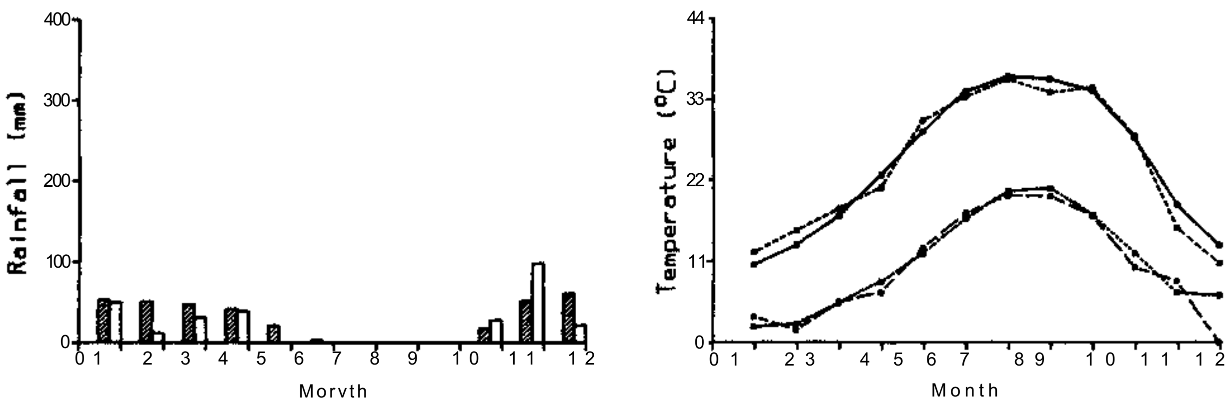




Chitedze. Rainfall was similar to 1982/83, 683 mm from December 1983 to May 1984, but unfavorably distributed, with less rain and dry spells in January and late March. Total rainfall in April was only 13,1 mm compared to 42.5 in the previous season.



Bulawayo. Rainfall was lower in 1984 than in a normal year with far less rain than usual in January and February.



Tel Hadya. This year the winter was dry and warm with 200 mm rainfall, 30% less than normal. Drought conditions extended into spring.

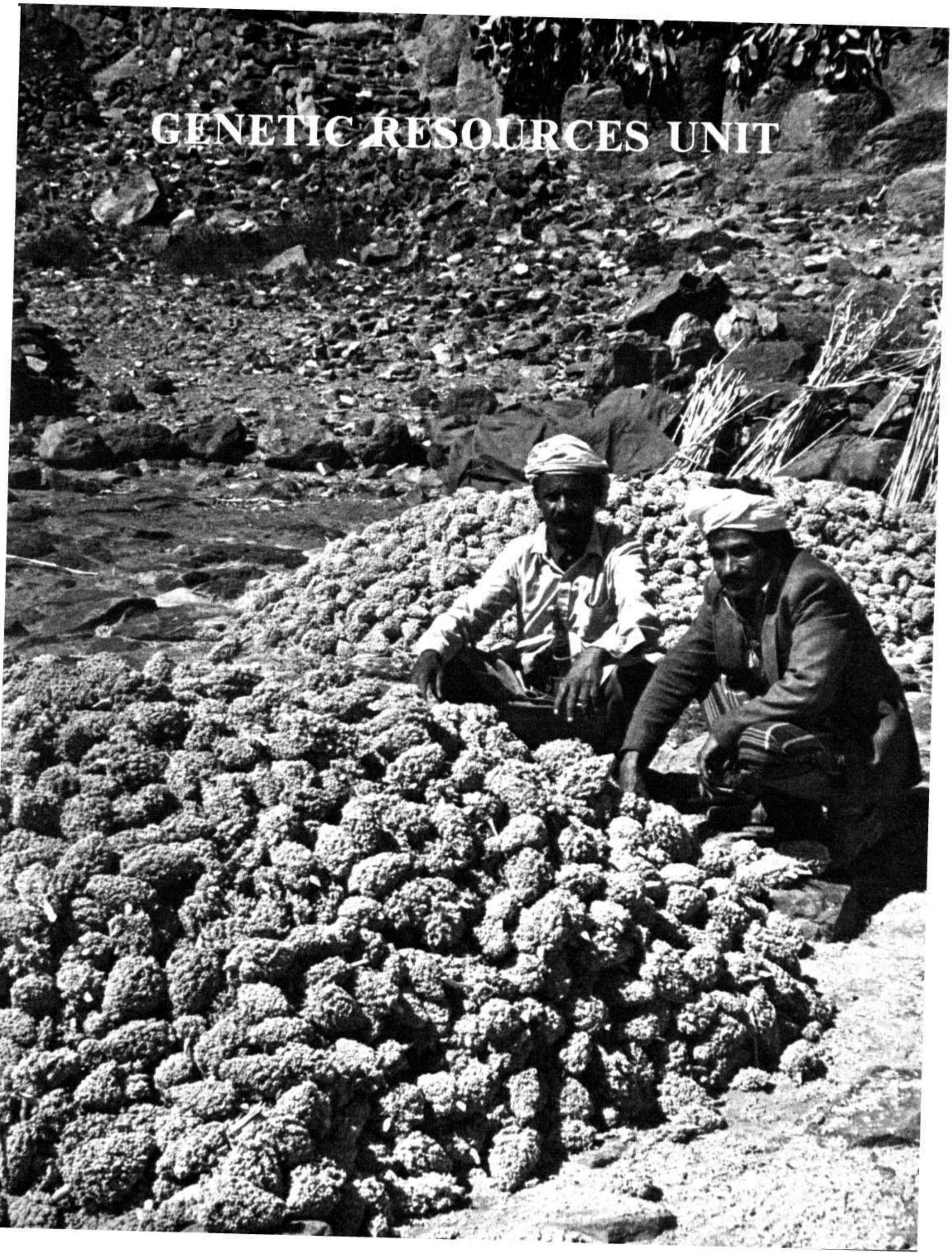
ICRISAT Plant Material named by the Plant Material Release Committee (PMRC), 1983-84

Notice	Crop	Type of material	Original name	New name	Justification
84/1	Pearl millet	Variety	WC-C75	ICMV 1	High-yielding variety released for general cultivation in India by Government of India, Ministry of Agriculture, Department of Agriculture and Cooperation.
84/2	Pearl millet	Variety	IBV 8001	ICMV 2	High-yielding cultivar in pre-release stage in Senegal.
	"	"	IBV 8004	ICMV 3	"
84/3	Pearl millet	Male-sterile lines (A and B)	2068A 8A(843A)	ICMA 2	New male-sterile line for the production of new hybrids.
	"	"	2068B 8B(843B)	ICMB 2	"
	"	"	2221A 1A(842A)	ICMA 3	"
	"	"	222 IB 1B(842B)	ICMB 3	"
	"	"	S10A (834A)	ICMA 4	"
			S10B(834B)	ICMB 4	"
84/4	Pearl millet	Inbred line	ICMPE 13-6-27	ICML 1	Source of resistance to ergot (*Claviceps fusiformis).*
	"	"	ICMPE 13-6-30	ICML 2	"
	"	"	ICMPE 134-6-25	ICML 3	"
	"	"	ICMPE 134-6-34	ICML 4	"
84/5	Pearl millet	Inbred line	SSC PS 252-S-4	ICML 5	Source of resistance to smut (*Tolyposporium penkillariae).*
	"	"	ICI 7517-S-1	ICML 6	"
	"	"	EBS46-1-2-S-2	ICML 7	"
	"	"	EB 112-1-S-1-1	ICML 8	"
	"	"	NEP 588-5690-S-8-4	ICML 9	"
	"	"	P 489-S-3	ICML 10	"
84/6	Pearl millet	Population (sibs of sister lines)	ICMPES 1	ICMP 1	Source with combined resistance to ergot *(Claviceps fusiformis),* smut *(Tolyposporiumpenicillariae),* and downy mildew *(Sclerospora graminicola)*
	"	"	ICMPES 2	ICMP 2	"
	"	"	ICMPES 28	ICMP 3	"
	"	"	ICMPES 32	ICMP 4	"
84/7	Pearl millet	Inbred line	IP 2696-1-4	ICML 11	Source of resistance to rust *(Puccinia penniseti)* controlled by a single dominant gene.

Continued

Notice	Crop	Type of material	Original name	New name	Justification
84/8	Sorghum	Pure line	SPV 351	ICSV 1	Released cultivar in India.
84/9	Chickpea	Pure line	ICCC 4	ICCV 1	Released cultivar in Gujarat State, India.
84/10	Chickpea	Pure line	ICCL 82001	ICCV 2	Combines acceptable kabuli seed-type with wilt resistance and short duration.
	"	"	ICCL 83006	ICCV 3	"
	"	"	ICCL 83004	ICCV 4	"
	"	"	ICCL 83009	ICCV 5	"
84/11	Pigeonpea	Line	ICP 8863	ICPV 1	Recommended by AICPIP as source of resistance to wilt *(Fusarium udum).*
84/12	Pigeonpea	Population	MS4A	ICPP 1	Source of translucent anther-type of male sterility.
84/13	Pearl millet	Inbred line	P7	ICML 12	Source of resistance to downy mildew *(Sclerospora graminicola).*
	"	"	SDN 503	ICML 13	"
	"	"	700251	ICML 14	"
	"	"	700516	ICML 15	"
	"	"	700651	ICML 16	"
84/14	Pearl millet	Inbred line	700481-21-8	ICML 17	Source of resistance to rust *(Puccinia penniseii).*
	"	"	IP 537 B	ICML 18	"
	"	"	IP 11776 (Souna Mali)	ICML 19	"
	"	"	IP 2084-1	ICML 20	"
	"	"	P 24	ICML 21	"
	"	"	D 212-P1	ICML 22	"
84/15	Sorghum	Pure line	SPV 386	ICSV 2	Released cultivar in Zambia.

GENETIC RESOURCES UNIT



Contents

Cover photo: Farmers with their sorghum harvest in the Yemen Arab Republic where ICRISAT collected sorghum germplasm in 1984 in collaboration with the Ministry of Agriculture.

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GENETIC RESOURCES UNIT

Germplasm is an important raw material for any crop improvement program, yet it is constantly faced with extinction. Before the newly-bred, high-yielding varieties reach the farmer, there is a need to collect his centuries-old, traditional landraces that will otherwise be replaced and permanently lost. The adoption of even a single successful new cultivar may wipe out the diversity achieved over centuries of natural and human selection.

Since it is an irreplaceable and invaluable heritage, germplasm must be collected, conserved, protected, and shared freely for present and future use. For this, international institutes like 1CRISAT, in collaboration with national and international organizations, have a unique role because their global perspective of plant genetic resources enables them to assess vulnerability to erosion, and to assign priorities to crops and areas that must be collected before germplasm diversity is lost forever.

The general objectives of the Genetic Resources Unit (GRU) are to collect, maintain, evaluate, document, conserve, and distribute germplasm.

We have made a number of germplasm collection missions in several centers of diversity, particularly in Africa, Asia, and South America. Wherever possible, the gaps in the world collections of our mandate crops are being filled by correspondence and exchanges with other gene banks and crop improvement scientists around the world.

The assembly of germplasm of ICRISAT mandate crops from all over the world and its distribution to scientists on request is channeled through the Central Plant Protection Training Institute (CPPTI), Ministry of Agriculture, Government of India, and is subject to quarantine regulations.

Present and Future Areas of Collection

The priority areas for our mandate crops, given below, are identified in collaboration with the International Board for Plant Genetic Resources (IBPGR), and ICRISAT and national scientists in germplasm resource areas.

Sorghum and Millets

Asia:	Burma, India, Indonesia, Nepal, Pakistan.
Eastern Africa:	Ethiopia, Kenya, southern Sudan, Uganda.
Southern Africa:	Lesotho, Mozambique, Swaziland, Zimbabwe.
West Africa:	Benin, Burkina Faso, Chad, Ghana, Ivory Coast, Mauritania, Nigeria, Togo.
Other areas:	Angola, Central African Republic, China, Congo, Egypt, Korea, Morocco, Saudi Arabia, Syria, Turkey, Yemen Arab Republic (YAR), People's Democratic Republic of Yemen (PDR), Zaire.

Chickpea

South Asia:	Bangladesh, Burma, India, Pakistan.
Southwest Asia:	Afghanistan, Iran, Turkey.
Central Asia:	USSR.
Africa:	Ethiopia, parts of northern Africa.

Pigeonpea

Asia:	Bhutan, Burma, China, India, Indonesia, Philippines, Thailand.

Eastern Africa:	Uganda.
Central and southern Africa:	Angola, Zaire.
West Africa:	To be explored.
Americas:	Caribbean Islands, South America.
Australia:	Northern Territory, Queensland.

Groundnut

Asia:	Burma, China, India, Indonesia, Thailand.
Eastern Africa:	Ethiopia, Malagasy Republic, Malawi, Tanzania, Zambia.
West Africa:	Chad, Ghana, Ivory Coast, Mali, Niger.
Northern Africa:	Egypt, Sudan.
South America:	Brazil, Ecuador, Paraguay, Peru, Uruguay, Venezuela.

New and important collection areas are identified annually based on fresh information received about genetic erosion, diversity, and degree of representation in the ICRISAT gene bank.

So far we have assembled 24604 sorghum germplasm accessions from 82 countries, 17081 pearl millet germplasm accessions from 37 countries, 13 818 accessions of chickpea from 40 countries, 10 104 accessions of pigeonpea from 37 countries, and 11488 accessions of groundnut from 82 countries (Table 1). We have also assembled 4992 minor millets accessions (Table 2). In view of the diversity areas yet to be covered, the number of samples is still small, although it represents the largest collection of ICRISATs mandate crops assembled and conserved at any one place. This material is well maintained and readily available to crop improvement scientists throughout the world.

Evaluation, screening, and identification of new and useful genetic traits are progressing well. These activities are continuing in close collaboration with all ICRISAT crop improvement

Table 1. Additions to ICRISAT germplasm collection in 1984, and cumulative totals, 1972 to 1984.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
AFRICA					
Benin	193	-	-	-	-
Burkina Faso	-	353	-	-	-
Burundi	70	-	-	-	-
Cameroon	-	20	-	-	-
Congo	-	3	-	-	-
Ethiopia	217	1	-	-	-
Kenya	104	-	-	143	-
Malawi	6	-	-	3	-
Mali	550	-	-	-	2
Morocco	-	-	1	-	-
Mozambique	-	-	10	-	-
Nigeria	-	86	-	-	52
Rwanda	70	-	-	-	-
Senegal	-	-	-	-	148
Sierra Leone	-	-	-	-	4
South Africa	109	68	-	-	9
Sudan	23	45	-	-	9
Tanzania	-	-	-	54	40
Togo	258	-	-	-	-
Zambia	-	-	-	-	58
Zimbabwe	-	88	-	-	57
ASIA					
Afghanistan	-	-	2	-	-
Cyprus	-	-	22	-	-
India	-	333	180	216	53
Iran	-	-	574	-	-
Korea	-	1	-	-	-
Nepal	-	-	1	-	-
Pakistan	-	3	2	-	-
Philippines	-	-	-	17	-
Sri Lanka	-	-	-	1	-
Syria	-	-	3	-	-
Turkey	-	1	3	-	-
Vietnam	-	-	-	-	3
Yemen Arab Republic	30	-	-	-	-
EUROPE					
Federal Republic of Germany	-	1	-	-	-
German Democratic Republic		-	-	1	-
Spain	-	-	32	-	-
UK[1]	76	27	-	-	-
USSR	-	-	2	-	

Continued

Table 1. *Continued*

Origin	Sor-ghum	Pearl millet	Chick-pea	Pigeon-pea	Ground-nut
THE AMERICAS					
Brazil	-	1	-	-	-
Mexico	-	-	5	-	-
USA	-	28	-	-	488
AUSTRALIA					
Australia	-	-	-	11	-
UNKNOWN	-	-	4	-	-
Total in 1984	1706	1059	831	456	923
Cumulative total[2]	24604	17081	13818	10104	11488

1. Material from several countries forwarded from the Royal Botanic Gardens, Kew, UK.
2. All crops 82087.

Table 2. Additions to minor millets collection in 1984, and cumulative totals, 1976 to 1984.

Species	Accessions in 1984	Cumulative total
Eleusine coracana (finger millet)	350	1863
Setaria italica (foxtail millet)	14	1260
Panicum miliaceum (proso millet)	16	753
Panicum sumatrense (little millet)	7	291
Echinochloa crusgalli (barnyard millet)	93	517
Paspalum scrobiculatum (kodo millet)	-	308
Total	480	4992

scientists. Some of the most exciting and promising results are the fruits of these interdisciplinary efforts. Several desirable genetic stocks, e.g., the drought-resistant sorghums IS 13441 (Zimbabwe), IS 20969 (Kenya), IS 22380 (Sudan), and IS 1347 (Egypt) have been identified, and some are already being used in current breeding programs. Germplasm conversion has made it possible for breeders to utilize photoperiod-sensitive tropical germplasm. Our introgression work transfers desirable traits from wild species to adapted cultivars.

All germplasm is now stored in medium-term cold storage at +4°C and 35 to 40% relative humidity. Our latest germination tests show that after 3 years' storage, 90% of the seeds are viable and germinate.

Germplasm Distribution

The supply of seed material to scientists worldwide is one of the major responsibilities of ICRISAT. Requests for germplasm accessions from the semi-arid tropics (SAT) are increasing every year. GRU supplies available samples free of charge to all national programs.

During the year 35 298 samples were distributed to scientists at ICRISAT Center, 8914 samples to scientists in India, and 20776 samples to scientists in 85 other countries (Table 3).

Sorghum Germplasm

This year 1706 new accessions were rejuvenated and added to the sorghum gene bank, raising the

Table 3. Germplasm samples distributed in 1984.

Crop	ICRISAT Center (1)	Within India (2)	Other countries (3)	Total samples distributed (2+3)	No. of countries
Sorghum	17477	2123	14668	16791	23
Pearl millet	3317	147	3651	3798	17
Chickpea	2844	4889	1707	6596	18
Pigeonpea	3467	1164	452	1616	22
Groundnut	8193	591	298	889	11
Total	35298	8914	20776	29690	91

Large, compact panicles of highland sorghum with big, light yellow grain collected during an expedition to the Yemen Arab Republic, 1984.

total to 24604. The new accessions were assembled by collection and correspondence from Benin (193), Burundi (70), Ethiopia (217), Kenya (104), Malawi (6), Mali (550), Rwanda (70), South Africa (109), Sudan(23), Togo (258), and the Yemen Arab Republic (30). Seventy-six samples, for which collection details are awaited, were received from the Royal Botanic Gardens, Kew, UK. A large part of the collection this year was from West African countries through the collection missions organized by the Institut francais de recherche scientifique pour le developpment en cooperation (ORSTOM).

A collection expedition was organized in the Yemen Arab Republic in collaboration with the Ministry of Agriculture, and 171 samples of sorghum representing the variation in high (1500-2500 m), medium (500-1500 m), and low (0-500 m) altitude regions were collected. This country has a wealth of sorghum landraces with a wide range of variation for panicle and grain size. Most of the landrace cultivars belong to the Durra, Durra-caudatum, and Durra-guinea races. Highland sorghums have large compact panicles, and big grain with good yield potential. Lowland sorghums mature during high temperature and humidity conditions that are ideal for grain mold infection. However, we collected a dual-purpose landrace locally named Khaira, used both for grain and as fodder. It has clean grain indicating possible resistance to grain mold infection.

A total of 2048 accessions from Cameroon (98), Cape Verde Islands (1), China (13), Ethiopia (2), France (314), German Democratic Republic (3), Hungary (75), Kenya (7), Morocco (5), Sierra Leone (99), South Africa (68), USA (1089), and Zimbabwe (274) were grown in the postentry quarantine isolation area (PEQIA) for inspection and release.

To meet increasing requests for seed, we rejuvenated 6074 accessions by selfing during the postrainy season. All the accessions are now conserved in medium-term cold storage. During the postrainy and rainy seasons, 1706 newly-assembled accessions were characterized and evaluated at ICRISAT Center, using ICRISAT/IBPGR sorghum descriptors.

We supplied 17477 seed samples to scientists in the Sorghum Improvement Program to be screened for resistance to insects, diseases, and drought, and for use in breeding programs.

We supplied 2873 accessions for use as base material to the ICRISAT Southern African Development Coordination Conference (SADCC) program recently started in Zimbabwe. This material includes 261 promising selections from our conversion program.

We continued our conversion program that involves the transformation of tall, photoperiod-sensitive tropical landraces to short, day-neutral background plants using a backcross breeding procedure. This program promotes the flow of tropical germplasm into breeding programs at ICRISAT Center and other national programs. F_4 and F_5 backcross populations involving Zerazera landraces grown at ICRISAT Center in 1984 produced promising segregants, and fairly uniform progenies; nearly 1386 selections were made by breeders and/or trainees from different countries, as well as by representatives of private seed companies who visited ICRISAT Center. Single-cross F_2 populations involving Kaura, Farafara, and Guineense landraces from

Nigeria have produced desirable segregants (although in a low proportion) with early duration and short plant height, that retain other landrace characters. Selected plants will be used for backcrossing in the conversion program.

The herbarium of cultivated sorghum races at the Royal Botanic Gardens, Kew, UK, assembled by Snowden prior to 1935, has been studied in detail in order to develop a new'subrace classification system' at ICRISAT Center.

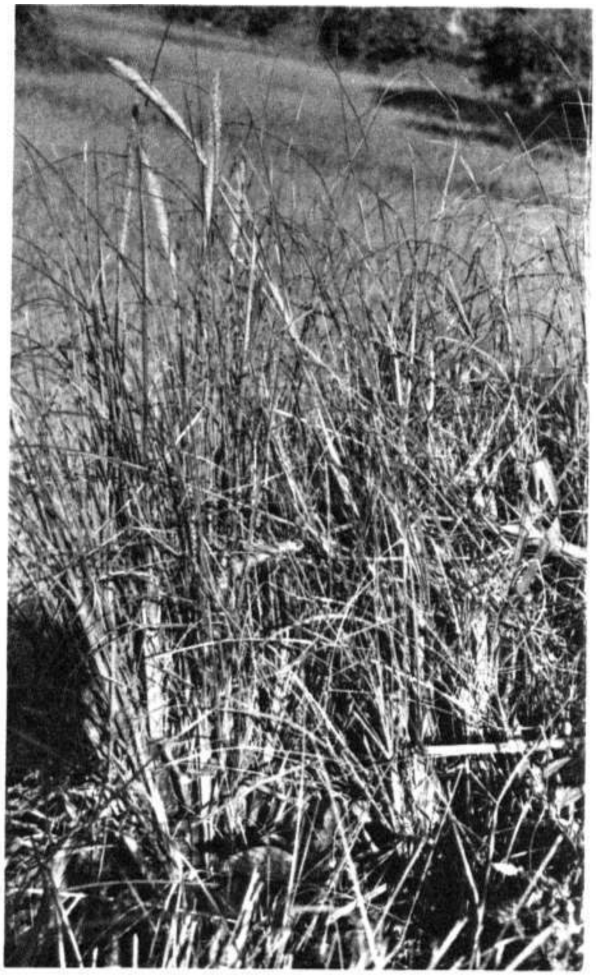
Pearl Millet Germplasm

During the year we added 1059 accessions to the already-existing 16 022, raising the total accessions in our gene bank to 17 081. The new additions are from Brazil (1), Burkina Faso (353), Cameroon (20), Congo (3), Ethiopia (1), German Democratic Republic (1), India (333), Korea (1), Nigeria (86), Pakistan (3), South Africa (68), Sudan (45), Turkey (1), UK (27), USA (28), and Zimbabwe (88).

An expedition to the hilly areas of the Eastern Ghats in India, inhabited by several tribal communities, yielded 109 primitive cultivars of pearl millet, and 4 accessions of *Pennisetum hohenackeri,* a wild species of *Pennisetum.* Among the cultivated pearl millets there are two distinct types—early- and late-maturing. Early-maturing millet is locally called 'Pitta ganti' and is usually grown as a transplanted crop. The grain is small, and elongated, with corneous endosperm. The late-maturing type is usually grown on hill slopes by the 'Savara' community. The whole grain is cooked like rice. Dried leaves of *Pennisetum hohenackeri* are used to make rope for weaving cots.

We rejuvenated 2419 accessions for which the

ICRISAT botanist collecting primitive pearl millet cultivars in Araku valley, Eastern Ghats, India, 1984.



Pennisetum hohenackeri (above), a wild millet growing in the Eastern Ghats, India, used by the local farmers to make rope for weaving cots (below).

seed quantity was depleted. We evaluated 1303 new introductions including the 1983 collection from Punjab.

For quarantine inspection and seed increase 498 accessions from Cape Verde Islands (1), France (6), German Democratic Republic (2), Mali (3), Morocco (3), Niger (1), Nigeria (436), Senegal (5), South Africa (31), USA (8), and USSR (2) were sown in the PEQIA. These include the accessions collected by ICRISAT scientists from northern Nigeria in 1983, South Africa in 1982, and the three pairs of male-sterile lines developed by ORSTOM. The 58 accessions from Sierra Leone sown in February 1983 did not flower until October indicating their strong daylength sensitivity. Of the seven accessions from Sudan sown in February 1983, *Pennisetum purpureum* did not flower till mid-November, while four of the cultivated accessions segregated for early- and late-maturing types.

Male-sterile lines identified from the Ghana and Botswana germplasm accessions were found to have downy mildew resistance. Test crosses were made with ICRISAT millet pollinators, several restorer (41) and maintainer (33) lines were identified, and eight hybrids were developed for further testing.

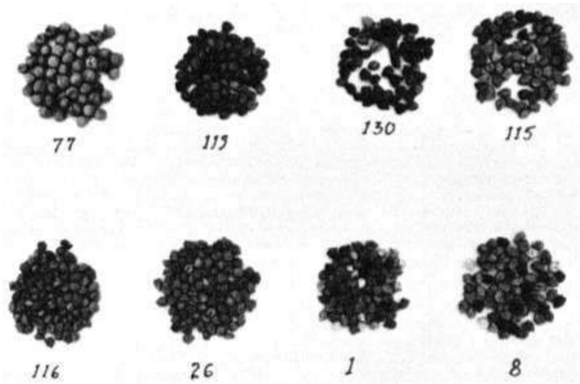
During the course of pearl millet germplasm evaluation at ICRISAT Center, naturally-occurring, viable mutants affecting chlorophyll development were isolated and maintained by selfing. Genetic studies conducted on the nature of inheritance of different striped characters established that in each case the mutant condition is governed by a single recessive gene. As most of the mutants can be identified at germination, they can be very valuable as seedling markers for mapping chromosomes.

In collaboration with the ICRISAT Pearl Millet Improvement Program, we evaluated 220 accessions from Ghana and Togo at ICRISAT Center, Hisar, and Bhavanisagar to identify lines for further utilization. From the quarantine grow-out, single-plant selections were made by the breeders mainly for grain color and size. Agronomically-superior lines were selected from the postrainy season grow-out. Early and dwarf mutants induced from tall and late-maturing

West African germplasm accessions were also selected for yield potential testing.

Chickpea Germplasm

In collaboration with the Plant Genetic Resources Center of Ethiopia, we collected 210 chickpea samples in 1982 and 104 in 1984 from chickpea-growing provinces of Ethiopia. The northeastern region of the country is still to be collected. Chickpea populations were extremely heterogeneous and will be subsampled to make them uniform. During the year, 831 numbers were registered in the gene bank of which several



Chickpea seeds collected in Ethiopia showing heterogeneity in samples from individual plots.

Member of the 'Savara' community in the Eastern Ghats, India, showing a late-maturing type of pearl millet that is cooked like rice.

came from the United States Department of Agriculture (USDA) gene bank. At present accessions number 13818 representing 40 countries.

We continued characterization and evaluation at ICRISAT Center and Hisar; 5525 entries were sown, and 3686 evaluated. Nearly all entries at Hisar were damaged due to soil problems. At ICRISAT Center, certain germplasm sets, landraces, and dry root rot -resistant accessions were evaluated in replicated trials. The grain yield performance of some accessions was better than the controls. In a test of induced mutants, six progenies outyielded the parent cultivar, Chafa. Some mutant progenies also showed promise of fusarium wilt resistance.

In the short cool season at ICRISAT Center from October to March, it is difficult to increase seeds of long-duration chickpeas. With extended daylength using artificial light, early flowering was induced and we could satisfactorily maintain those accessions and the wild species.

Chickpea-related disciplines at ICRISAT Center screened germplasm accessions for resistance to colletotrichum blight (6140), stunt virus (338), *Heliothis armigera* (528), and for higher protein content (1147). Breeders selected and evaluated 204 accessions for better adaptation to early sowing. Physiologists screened 1696 accessions at Hisar to select management-responsive

Using artificial light at ICRISAT Center to extend the daylength for long-duration chickpea accessions. By this method we induced early flowering and obtained better yields.

and cold-tolerant genotypes. Biochemists working on seed quality analyzed 100-g samples of decorticated, dried, split chickpea seeds (dahl). They determined protein percentages and found in 1147 samples a range of 19.1 to 33% (mean 24.2%). They also determined methionine content in 500 samples and found a range of 0.157 to 0.490g methionine (mean 0.276g), in each 100-g sample.

Passport data of 13 818 accessions and characterization data of 12 500 accessions have been entered into the computer, and information is retrievable for users.

Our germplasm users abroad indicated that chickpea is a promising crop in Sri Lanka, Philippines, and Belize. Chickpea may be a new introduction in these countries.

Pigeonpea Germplasm

The world collection of pigeonpea germplasm now consists of 10 104 accessions from 37 countries, with the addition in 1984 of 456 accessions from Australia (11), Federal Republic of Germany (1), India (216), Kenya (143), Malawi (3), Mozambique (10), Philippines (17), Sri Lanka (1), and Tanzania (54). In 1984 we sowed 287 exotic lines in the PEQIA for seed increase and release. They included 221 lines from Malawi, 24 from the West Indies, 14 from Ethiopia, 13 from Nigeria, 6 from Cape Verde Islands, 4 from South Africa, 3 from Sierra Leone, and one each from China and the German Democratic Republic.

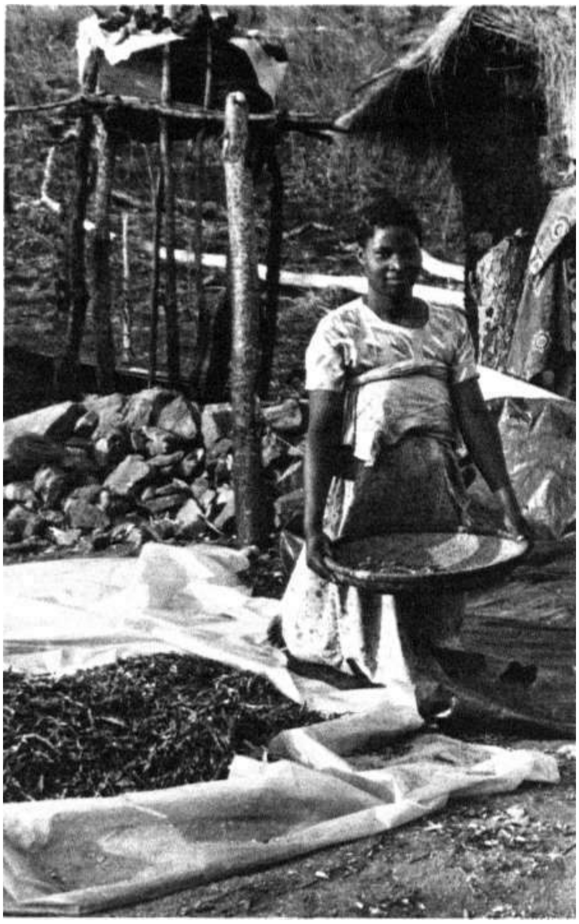
In 1984 we grew 1122 lines for characterization. Good plant stand enabled us to record morphoagronomic traits from over 1100 lines. We began characterizing the early pigeonpeas at Hisar in 1983. In our first attempt we secured data on 224 of the 278 early lines we grew there. In 1984 a further set of 19 extra-early and 294 early lines were grown at Hisar. All lines established well and data are being recorded. Days to 50% flowering vary from 70 to 131 and plant height varied from 105 to 295 cm. This once again confirms that maturity classification based on observations recorded at one location may not necessarily hold good at other locations.

From the long-duration lines, we selected 60 land races with impressive agronomic traits and conducted a preliminary evaluation of these traits. Most of the lines of this set were also evaluated at Vizianagaram in collaboration with the Andhra Pradesh Agricultural University (APAU), and the ICRISAT cooperative research station at Gwalior.

We grew 935 lines for rejuvenation. Plant stand and flowering were excellent and we expect to secure enough quantities of seed to meet the needs of our clients. All wilt-resistant lines were raised in wilt-sick plots for rejuvenation and further testing.

To identify pigeonpeas with less photoperiodic sensitivity, we conducted preliminary screening of 1080 lines by sowing at different periods in 1983/84, starting in mid-November. All except 14 lines were found to be sensitive. Elite lines chosen from preliminary screenings are tested for photoperiodic insensitivity under extended daylength and in 1983/84, a set of 400 lines were screened. Of these, 395 lines flowered, though the days to flowering varied compared to the control. All the control lines also flowered. The test gave us a further opportunity to purify lines which were segregating for photoperiodic insen-

Wild annual species of *Cicer* showing variations in plant and seed morphology.



Threshing pigeonpeas in Malawi. Samples from this country sent to ICRISAT Center in 1984 provided good sources of genes for improving vegetable types.

sitivity. During 1984, 400 lines of another set were grown under extended daylength to screen against photoperiodic insensitivity and for purification.

Pathologists screened 190 lines for resistance to wilt *(Fusarium udum)* and sterility mosaic diseases, and 2079 lines for phytophthora blight *(Phytophthora drechsleri* f. sp. *cajani),* and entomologists screened 81 lines for insect resistance. A total of 258 lines were analyzed by the Biochemistry Unit to record seed protein content. It varied from 15.2 to 24.0%, with a mean of 20.0%.

We assembled through correspondence and collection a number of wild relatives of pigeonpea. These included 11 species of *Rhynchosia* from Malawi and South Africa, 3 species of *Atylosia* from Australia and Ethiopia, and an *Eriosema* species from Ethiopia. All these are now in our isolation field. At present the wild gene pool consists of 192 accessions representing 46 species and 6 genera.

To rejuvenate wild species accessions and utilize some of them for introgression, a total of 21 accessions belonging to 11 species and 2 genera were raised in the ICRISAT Botanical Garden.

We confirmed male sterility in two accessions which are now being grown for seed increase.

Passport data of all registered accessions and evaluation data of all evaluated lines are now available in an easily-retrievable computer system.

Groundnut Germplasm

During 1984 we continued to collect and assemble groundnut germplasm, raising our total accessions to 11 488. The introductions included material collected by other organizations from USA (205, including 10 wild *Arachis* species), Zambia (58), and Sudan (9), and assembled from known resource centers e.g., Centre National de Recherches Agronomiques (CNRA), Bambey, Senegal (148); Southern Regional Plant Introduction Station (SRPIS), Experiment, Georgia, USA (274), and Crop Breeding Institute, (CBI), Harare, Zimbabwe (57). The accessions collected by ICRISAT scientists in India (23) in 1984, and in Nigeria (52), Sierra Leone (4), and South Africa (9) during 1983 were released through quarantine during 1984. Most of the introductions were multiplied during the rainy season and a few of them were planted during the postrainy season. These new accessions have contributed to a significant increase in the available groundnut variability in ICRISAT's gene bank.

In collaboration with the Centro Nacional de Recursos Geneticos (CENARGEN) of Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), the Inter-American Institute for Cooperation on Agriculture (IICA), and 1BPGR, a collection mission was undertaken from 10 to 28

April, in Mato Grosso do Sul State, Brazil, which is one of the main centers of diversity for *Arachis.* A total of 73 *Arachis* samples were collected and an additional 31 populations were sampled for the herbarium. *Rhizohium* nodules were obtained from 27 *Arachis* populations. The species collected belonged to three sections—*Arachis, Erectoides* (series *Trifoliolatae* and *Tetrafoliolatae),* and *Rhizomatosae.* We collected one accession which could be a new species in section *Arachis.* We also obtained information on conservation of the species in their natural habitat, and on the occurrence of pests and diseases. It appears that *Arachis* may be infected by various diseases to a higher degree than was previously thought.

During the rainy season 2698 accessions including 146 new arrivals were grown for seed increase as well as for characterization of various morphoagronomic characters using the ICRISAT/IBPGR groundnut descriptors. During the postrainy season 3157 accessions including 490 new introductions were grown, mainly for rejuvenation and seed multiplication. In collaboration with ICRISAT groundnut scientists we screened about 8000 accessions for insect, disease, and drought resistances. Preliminary results indicate new sources of resistance to, or tolerance of, rust *(Puccinia arachidis),* yellow mold *(Aspergillus flavus),* and leaf miner *(Aproaerma modicella).* Seventy-three wild species accessions were grown for seed increase because of increased demand for evaluation and utilization.

Documentation has been further strengthened by computerizing passport data for 33 descriptors for 10 000 accessions, and computerization of evaluation data is in progress.

A short-petiole mutant (ICG 10145) was identified and found to be true breeding. The inheritance of this character is being studied in collaboration with groundnut breeders.

ICG 10145, a true-breeding, short-petiole mutant identified from our accessions. We are now studying the inheritance of this character with ICRISAT groundnut breeders.

Minor Millets Germplasm

A total of 480 new accessions of five crop species (Table 2) received from Burundi, India, Japan, Mexico, Mozambique, Sudan, Tanzania, UK, Zambia, and Zimbabwe were rejuvenated during the year raising the total gene bank holdings to 4992. The National Plant Quarantine Service released 180 accessions from: Hungary (104), Kenya (56), and South Africa (20). They are in the PEQIA awaiting release.

Using funds provided by 1BPGR, we worked on the *Setaria italica* and *Panicum miliaceum* accessions held in our collection, and characterized and classified 1256 accessions of foxtail and 750 accessions of proso millets.

We distributed 200 seed samples of finger millet (*Eleusine coracana)* to Uganda.

Looking Ahead

The collection program will be further accelerated depending on the availability of resources. More specific and pointed collections will be made in areas where important genetic traits have been identified. In all cases our collection programs will be undertaken in close collaboration with national programs and scientists.

In order to promote a safe and proper germplasm collection, evaluation, conservation, and utilization program, it has been proposed to establish regional genetic resources activities for Africa and the Americas. The first such regional program will be initiated at the ICRISAT Sahelian Center (ISC), Niger.

We will also expand our research activities in the areas of germplasm viability, genetic studies, the effect of long-term cold storage on the genetic and cytogenetic aspects of our crops, the effect of insecticides and fungicides on seed viability of conserved germplasm, and will search for new desirable genes, genetic markers, and their mode of inheritance. The possible use and application of other methods of germplasm conservation and maintenance, such as liquid nitrogen and in vitro culture techniques represents potential work in the future.

Our introgression work to incorporate resistance genes from wild relatives will be given more emphasis in the future. In general, we will attempt to give more attention to the conserved material, not only to monitor its viability, but also to undertake specific research work on the stored material. Long-term storage of seeds at a temperature of -18°C in sealed containers is planned to enable us to preserve the original samples without subjecting them to frequent rejuvenations. Progress has been made in the construction of storage chambers, but the equipment has yet to be installed.

Publications

Journal Articles

Appa Rao, S., Mengesha, M.H., and Raja Gopal Reddy, C. 1984. Characteristics and inheritance of viable chlorophyll mutants in *Pennisetum americanum* (L.) Leeke. Indian Journal of Botany 7:1-5.

Bharatan, N., Reddy, D.V.R., Rajeswari, R„ Murty, V.K., Rao, V.R., and Lister, R.M. 1984. Screening peanut germplasm lines by enzyme-linked immunosorbent assay for seed transmission of peanut mottle virus. Plant Disease 68:757-758.

de Wet, J.M.J., Prasada Rao, K.E., and Brink, D.E. 1983. Systematics and domestication of *Panicum sumatrense* (Gramineae) Journal d'agriculture Traditionnelle et de Botanique Appliquee. 30 (2):159-168.

de Wet, J.M.J., Prasada Rao, K.E., Brink, D.E., and Mengesha, M.H. 1984. Systematics and evolution of *Eleusine coracana* (Gramineae). American Journal of Botany 71(4):550-557.

Maiti, R.K.,Prasada Rao, K.E., Raju, P.S., and House, L.R. 1984. The glossy trait in sorghum: its characteristics and significance in crop improvement. Field Crops Research 9:279-289.

van der Maesen, L.J.G., and Pundir, R.P.S. 1984. Availability and use of wild *Cicer* germplasm. Plant Genetic Resources Newsletter (IBPGR) 57:19-24.

SORGHUM

Contents

Cover photo ; Using a steady-state porometer to measure the diffusive resistance of sorghum leaves during a drought experiment at ICRIS AT Center.

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SORGHUM

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

Our global sorghum research activities are concentrated at ICRISAT Center, our Cooperative Regional Programs in West, eastern and southern Africa, and in Central America and Mexico. This report covers research results from 1984 as well as those from 1983 which could not be reported in the 1983 Annual Report.

In India, we used several locations where high stress factors occur regularly, to adequately screen germplasm accessions and breeding material for resistance to various stresses. The locations for stem borer and anthracnose disease are Hisar and Pantnagar, both in northern India; Anantapur in southern India for drought; Bijapur and Akola for *Striga asiatica,* Dharwad for sorghum downy mildew and midge, and Bhavanisagar (near Coimbatore) where we evaluate material for adaptation to latitudes near the equator.

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

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

Several of our varieties and hybrids were evaluated in advanced multilocational national trials and on farmers' fields in many countries. In India, ICSV I (SPV351) was released as CSV 11, and our sorghum hybrid SPH 221 was tested in minikit trials. In Guatemala, M 90975 and M 91057 were released as ICTA-C 25 and ICTA-C21.

Physical Stresses

Drought Resistance

Germplasm screening. We screened germplasm accessions and breeding lines for drought-resistant traits under severe environmental stress conditions during the 1983 and 1984 summer seasons at ICRISAT Center, and 1984 rainy season at Anantapur,

In 1983, a total of 700 selected germplasm collection entries and advanced breeding lines were screened during the summer at ICRISAT Center. The material was divided into three groups; the first two groups comprised germplasm collection lines selected from a wide range of taxonomic groups, geographical locations, and climates, while the third group included both germplasm collection lines, and 70 advanced breeding lines. The three groups of material, sown at monthly intervals starting in early February until April, were established with irrigation for 15-18 days. Irrigation was then discontinued, and stress was imposed.

We examined in detail the three traits indicated below:

1. Desiccation tolerance or avoidance, i.e., a measure of the amount of leaf area that remained unscorched or 'fired'. We scored leaf firing at regular intervals during the stress period on a 1 to 5 scale, where 1 = less than 20% leaves fired, and 5 = over 80% leaves fired.

2. Recovery resistance, i.e., ability of a line to continue to produce new leaves once the rains begin. We scored recovery resistance on a 1 to 5 scale, where 1 = over 80% recovered, and 5 = less than 20% recovered.

3. Agronomic score, i.e., the ability of a stressed line to produce grain when the rain comes.

We examined the results of the 1983 screenings and retained lines that had a leaf-firing score between 1 and 2.99 and 3.99 and 5, i.e, the lines most resistant and susceptible to leaf firing. Figure 1 shows the effects of stresses due to heat and lack of water on typically resistant and susceptible lines. We selected 266 lines for further screening in 1984. From the 1983 experiments we concluded that a March planting gave the most suitable and reliable selection pressure.

Figure 1. Effects of stresses due to heat and lack of water on two sorghum cultivars, IS 22327 (left), a resistant line from Botswana, and IS 12741 (right), a susceptible line from China, ICRISAT Center, 1984.

The 266 selected lines were sown on 16 March, 1984 in an Alfisol at ICRISAT Center in four replications. The crop was established with irrigation and stress imposed after 20 days. All the lines experienced stresses from heat and lack of water for a period of 66 days. During the stress period only 4.5 mm of rain fell, and the mean maximum temperatures were close to 40° C. The stress ended 88 days after emergence (DAE) following 21.6 mm of rain. We scored the material for leaf firing at 48, 61, 70, and 83 days after sowing (DAS), for recovery resistance at 89,94, 102, and 117 DAS, and for agronomic scores when the lines reached physiological maturity.

We observed 28 lines from various taxonomic groups originating from 12 countries with a range of altitudes and rainfalls to be both firing-resistant (FR), and able to recover from severe stress (RR) (Table 1). Three of these lines also had good grain yields. The group included two accessions IS 1347 from Egypt, and IS 13441 from Zimbabwe (Fig. 2) and an ICRISAT advanced hybrid, SPH 225. Seed of all the promising lines were sent to scientists in Australia, USA, and Zimbabwe for further evaluation under their growing conditions.

The same 266 lines were sown again on 13 July 1984 at Anantapur where the rains were poor in 1984 (151 mm rain during the growing season, and only 18.5 mm during the stress period). The mean maximum temperature at Anantapur was 30.4°C. Many lines were completely killed, but 10 lines were FR, and 27 RR after only 41 mm rain. Six lines were both FR and RR, and one of these, SPH 263, had a good agronomic score.

Table 1. Sorghum lines identified as having firing resistance (FR) and recovery resistance (RR) traits at ICRISAT Center, summer season 1984.

Entry	Origin	Elevation (m)[2]	Rainfall (mm)[3]	Taxonomic group
IS 8564	Chad	-[1]	-	Caudatum
IS 1347	Egypt	-	-	Caudatum bicolor
IS 1096	India	500	800	Durra
IS 22064	India	500	500	Durra
M 35-1	India	500	700	Durra
SPH 225	India	-	-	-
SPV 138	India	-	-	-
SPV 386	India	-	-	-
SPV 394	India	-	-	-
IS 18463	India	-	-	Kafir caudatum
IS 18465	India	560	800	Durra
IS 20965	Kenya	1100-1500	-	Drummondii
IS 20969	Kenya	1100-1500	-	Caudatum
IS 21479	Malawi	70	800	Guinea
IS 3898	Mali	-	-	Guinea bicolor
IS 23687	Mozambique	250	900	Guinea
IS 8344	Pakistan	-	-	Durra
IS 22380	Sudan	600	450	Caudatum
IS 3511	Sudan	-	-	Kafir caudatum
IS 9708	Sudan	-	-	Caudatum
IS 12737	Taiwan		-	Caudatum
IS 113	USA	-	-	Kafir caudatum
IS 121	USA	-	-	Kafir caudatum
IS 13441	Zimbabwe	-	-	Caudatum
IS 13446	Zimbabwe	-	-	Caudatum
CSH 5	India	-	-	-
CSH 8	India	-	-	-
CSH 9	India	-	-	-

1. Data not available.
2. Nearest known point to area of collection.
3. Mean annual rainfall in area of collection.

This hybrid also recovered from severe stress at ICRISAT Center. The two promising hybrids SPH 225 and SPH 263 will be evaluated in field scale trials at Anantapur in 1985.

Crop Establishment

High soil temperatures reduce seedling emergence in sorghum. We reported earlier (ICRISAT Annual Reports 1982, p.41 and 1983, p.19) a technique to study seedling-emergence response to high soil temperatures.

The Welsh Plant Breeding Station, UK, developed a technique to measure protein synthesis during germination where 10 embryo-containing half-seeds were incubated with 1 mL buffer [20 mM-Tris-HCl, pH 7.5, 5 mM $MgCl_2$ buffer, containing 0.03 $mg mL^{-1}$ chloramphenicol and 1u*Ci* (37 kBq) of a (U-^{14}C)] amino acid mixture. After 1 h the samples were removed, rinsed and blotted, then homogenized, extracted with 1 mL H_20, and centrifuged at 13 000 *g* for 5 min. Supernatant (100 u1) was spotted onto glass fibre discs, nonincorporated radioactive solution was washed off, and the discs were air-dried and counted in a toluene/Triton/PPO scintillant. Each sample was tested at temperatures between 30 and 40° C. Seed size variations were corrected by using soluble protein as the basis of expression.

Table 2 shows the emergence percentages of the entries at four soil temperatures using the method described in ICRISAT Annual Report 1982, p.41. Emergence generally decreased as temperatures increased, and at all temperatures varieties had higher emergence percentages than hybrids; e.g., there was a twofold difference in the mean emergence percentage between the lowest variety (SPV 386), and the lowest hybrid (CSH 1).

Figure 2. Sorghum cultivar IS 13441 from Zimbabwe with firing resistance and ability to recover from severe stress. This line has also produced good grain yields on large panicles (left).

Table 2. Effects of four soil temperatures (°C) on sorghum seedling emergence (%), laboratory test, ICRISAT Center 1982.

	Soil temperature (° C)			
	35	40	45	50
Entry	Seedling emergence (%)			
Hybrids				
CSH I	46	27	20	0
CSH 5	70	35	-[1]	-
CSH 6	70	40	-	-
Varieties				
SPV 354	85	70	67	0
SPV 386	90	83	15	0
SPV 387	90	65	50	0
CSV 5	73	93	80	0
SE	±6.2	±10.1	±13.0	
Mean	74.9	59.0	46.4	0
CV (%)	21	44	61	

1. Not tested at these temperatures.

Figure 3 shows the protein synthesis data, expressed as radioactive counts per minute incorporated into protein, for two varieties and two hybrids. The rates of amino acid incorporation at lower temperatures (37-38° C) were much higher in varieties (CSV 5 and SPV 386) but protein labelling diminished sharply after 38° C. The lower maximum rates of incorporation measured in the two hybrids were accompanied by a more gradual decline phase.

Sorghum is markedly affected by high temperature, as demonstrated by its effect on seedling emergence, and on the rates of embryo protein synthesis. The results from the experiments show that these two responses to temperature are closely related. Protein synthesis is therefore a prerequisite for seedling germination, and in sorghum, temperatures of 40° C and above inhibit both the rate of embryo protein synthesis, and seedling emergence.

The lower levels of protein synthesis and percentage emergence in the hybrids over the temperature range 30-40°C are important. It can be postulated that if a specific level of embryo protein synthesis is necessary for suc-

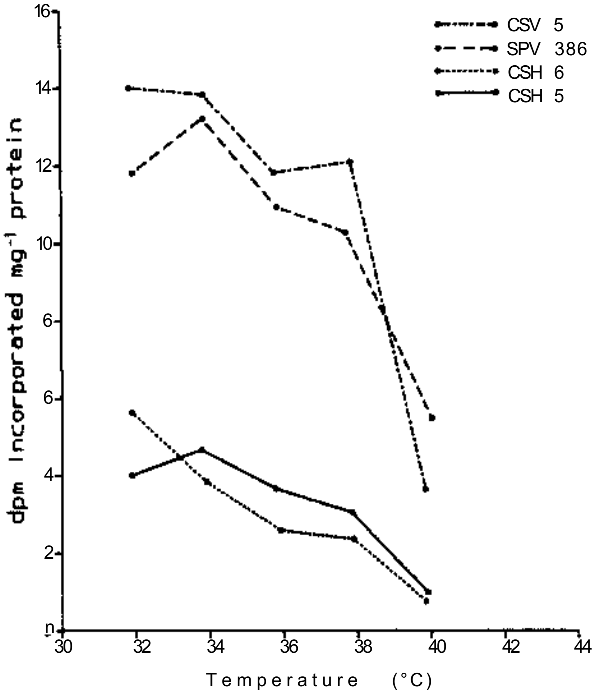


Figure 3. Embryo protein synthesis expressed as radioactive counts min^{-1} (dpm) incorporated mg^{-1} protein of sorghum varieties CSV 5 and SPV 386, and hybrids CSH 5 and CSH 6, during 16 h imbibition at different temperatures, Welsh Plant Breeding Station, 1982.

cessful germination and emergence, then hybrids would fall below a given value at a lower temperature than would varieties. This is also supported by the data in Table 2 which shows marked differences between the percentage emergence of hybrids and nonhybrids. We plan to conduct more studies involving a wider range of varieties and hybrids to better understand the reasons for this finding.

Biotic Stresses

Diseases

Grain Molds

Determining resistance by the ergosterol assay method. We normally rate sorghum lines from the ICRISAT screening nursery for resistance to grain molds by the following visual qualitative method based on the moldiness of the grain. Panicles and threshed grains are rated 14 days after physiological maturity, on a 1 to 5 scale, where 1 = no mold, and 5 = more than 50% grains in a panicle molded (for panicle grain mold rating, PGMR), or more than 50% grain surface area molded (for threshed grain mold rating, TGMR). While this method is rapid, and has been successfully used to identify resistant lines, it has certain disadvantages because: 1. it is not quantitative, and therefore subject to error through differences in perception of moldiness by different individuals, 2. grain colors other than white often interfere with mold appearance on the grain, and 3. fungal growth inside the grain is not considered.

To overcome these problems we evaluated the ergosterol assay method for determining resistance or susceptibility to sorghum grain molds. This method was developed by Dr. L.M. Seitz of the U.S. Grain Marketing Research Laboratory, Manhattan, Kansas, USA, to measure fungal biomass in cereal grains. The method is specific to fungi because among all plant and animal systems, ergosterol is present only in fungi as a structural component of the plasma membranes.

The seed ergosterol contents of sorghum lines from the 1983 rainy season grain mold screening nursery consisting of 31 resistant, 4 moderately-resistant, and 4 highly-susceptible genotypes were analyzed by Dr. Seitz. He also analyzed for comparison, seed of the same genotypes grown under irrigation during the 1983/84 post rainy season that was visually mold-free.

Results showed (Table 3) that six lines with ergosterol contents of up to 10 ppm, the threshold level for resistance, were also rated resistant by the visual assessment method. However six lines, IS 10892, IS 19953, IS 17141, IS 3585, IS 9498, and IS 21651, visually assessed as resistant, had ergosterol levels of 14.21 to 22.11 ppm indicating that they were damaged by molds. All the highly-susceptible and moderately-susceptible lines had high levels of ergosterol. Grain of SPV 104 was virtually a mass of fungal hyphae confirmed by its high ergosterol content.

These results confirm the usefulness of the

Table 3. Visual grain mold ratings and ergosterol content (ppm) of grains of selected sorghum genotypes, ICRISAT Center, rainy and postrainy seasons 1983.

Genotype	Visual mold score of rainy season grain		Ergosterol content (ppm)[4]	
	PGMR[1]	TGMR[1]	Rainy season grain	Postrainy season grain
IS 21454	1.9	2.0	3.09	0.19
IS 2454	2.0	2.0	3.75	-[2]
IS 20620	1.9	1.8	4.87	0.74
IS 14388	2.0	1.8	4.92	0.32
IS 14387	2.0	1.8	5.08	0.18
IS 2867	1.8	1.9	5.14	0.23
IS 10892	2.0	2.0	14.21	0.52
IS 19953	2.1	2.5	15.69	0.06
IS 17141	2.0	2.3	16.90	0.14
IS 634	2.4	3.5	19.86	-
IS 3585	2.0	2.7	20.58	-
IS 9498	2.0	2.1	20.92	0.05
IS 21651	2.2	2.2	22.11	-
IS 21901	2.0	3.1	28.04	-
IS 402	4.2	4.9	29.69	-
IS 417	4.4	4.5	30.12	-
IS 18758	4.0	3.5	40.98	0.07
IS 9832	2.0	3.8	42.67	-
Controls				
CSH 1	4.5	5.0	46.34	ND[3]
SPV 104	5.0	5.0	142.10	<0.03
SE	±0.09	±0.23	±1.73	-
Correlations				
PGMR		0.85**	0.76**	
TGMR			0.73**	

1. Ratings based on a 1 to 5 scale, where 1 = no mold, and 5 - more than 50% grains in a panicle molded (for panicle grain mold rating, PGMR), or more than 50% grain surface area molded for TGMR.
2. Data not available.
3. Not detectable.
4. Ergosterol content of rainy season samples used to compute correlations.

ergosterol assay method for determining resistance to grain molds. The method is quantitative, rapid, and reliable, but requires the use of High Performance Liquid Chromatography equipment (HPLC).

Resistance screening. Routine screening for grain mold resistance is conducted in a large-scale field nursery at ICRISAT Center (see ICRISAT Annual Report 1981, p.32). Sorghum lines identified as resistant in one year continue to be screened in the following years for stability of resistance. This year, in preliminary screening, we evaluated 182 germplasm accessions from the Genetic Resources Unit, and selected 51 colored-grain lines for further screening. In advanced screening, 76 colored-grain lines first identified as resistant in 1980, and 53 lines identified in 1982, were again found to be resistant.

Biochemical mechanisms of resistance. We made preliminary biochemical investigations on five cultivars and found that mold-resistant cultivars had much higher concentrations offlavan-4-ols than susceptible cultivars. We found a similar reaction when leaves of mold-resistant and mold-susceptible cultivars grown in the greenhouse and harvested at different stages of growth were analyzed for flavan-4-ols. However, callus tissues obtained from these contrasting cultivars did not exhibit any marked differences when analyzed for flavan-4-ols. Further work is in progress.

Breeding for resistance. We continued to screen progenies identified as mold resistant in 1983 (ICRISAT Annual Report 1983, p.22) with encouraging results. We screened 3452 F_3, 756 F_4, and 477 F_5 colored- and white-grain progenies, and identified 1090 mold-resistant individual colored-, or white-grain panicles with a TGMR of less than 3. In the same nursery, the white-grain, mold-susceptible varieties SPV 104 and SPV 351 were severely molded with a TGMR of 5. Table 4 shows the number, and TGMR of white-grain mold-resistant selections in the F_3, F_4, and F_5 generations from five crosses which gave the best results. We are advancing the highly mold-resistant selections to F_4, F_5, and F_6 generations during the postrainy season for further screening in the 1985 rainy season in

Table 4. Results of mold resistance screening of F_3, F_4, and F_5 progenies derived from crosses between mold-resistant, colored-grain sorghums and mold-susceptible, white-grain sorghums, ICRISAT Center, rainy season 1984.

Cross	Pedigree	Generation	TGMR[3] of white-grain panicle selections			Total selections
			1	2	3	
ICS x 810132	IS 14384[1] x SPV 351[2]	F_3	1	10	68	79
		F_4	0	11	42	53
		F_5	0	3	31	34
ICS x 810126	IS 14384 x SPV 104[2]	F_3	1	19	17	37
		F_4	0	36	51	87
		F_5	0	14	70	84
ICS x 810119	SPV 351 x IS 14385[1]	F_3	0	7	59	66
		F_4	0	27	84	ill
ICS x 810113	SPV 104 x IS 14385	F_3	0	2	10	12
		F_4	0	1	11	12
		F_5	0	1	3	4
ICS x 810062	IS 14388[1] x SPV 351	F_3	0	3	15	18
Total			2	134	461	597

1. Mold-resistant colored-grain parent.
2. White-grain, mold-susceptible parents, repeatedly grown in the nursery at every 10 progeny rows, TGMR = 5.
3. Grain mold score (TGMR) on a 1 to 5 scale, where 1 = no mold, 5 = severe mold with >50% grain surface area molded.

replicated trials at ICRISAT Center, and for testing at Bhavanisagar, a grain mold hot-spot location in southern India.

Multilocational testing. The 1983 International Sorghum Grain Mold Nursery (ISGMN) consisting of 27 test entries (all except IS 14332 with colored grain) and three susceptible controls was sent in two replications to cooperators at 17 locations in Africa, Asia, and the Americas. Data received showed that Bhavanisagar, Coimbatore, ICRISAT Center, Navsari, Pantnagar, and Udaipur (India), Samaru (Nigeria), and Laguna (Philippines), were the only locations where relative humidity and rainfall during grain development and maturity were adequate to promote mold development. Results from these eight locations were the only ones useful for evaluating resistance.

White-grain sorghum line IS 14332 (left) resistant to grain mold at Samaru (Nigeria), and six Indian locations in the International Sorghum Grain Mold Nursery, 1983. At right are moldy panicles from susceptible genotypes that mature at the same time as IS 14332.

At all eight locations, all the colored-grain entries including IS 14375 and IS 14384, that have no testa, and negligible amounts of tannins (ICRISAT Annual Report 1983, p.23), were resistant to grain molds. The white-grain entry IS 14332, resistant in previous nurseries, was again resistant at all locations except Laguna. The resistance of IS 14332 needs further investigation since the line is slightly photoperiod-sensitive, and its resistance may be due to avoiding weather conditions conducive to mold development.

Downy Mildew (*Peronosclerospora sorghi*)

Resistance screening. Routine screening of breeding lines and genetic resources accessions for downy mildew (DM) is conducted at Dharwad in southern India, using the large-scale field screening technique (ICRISAT Annual Report 1983, p. 28). This year we screened 4403 advanced generation breeding lines from various breeding projects, and 145 genetic resources accessions, and selected 869 breeding lines and 117 accessions for further screening. Among the breeding lines 17 came from international adaptation trials that consist of agronomically-elite varieties and hybrids with high yield potential.

Multilocational testing. The 1983 International Sorghum Downy Mildew Nursery (ISDMN) consisting of 19 entries, including two susceptible controls, one of which was a local entry, was sent to cooperatars at locations in Argentina, Botswana, Brazil, Ethiopia, Guatemala, Honduras, India, Mexico, Nigeria, Uganda, USA, and Venezuela. Results received from Argentina (2 locations), India (3 locations), Nigeria, and the USA confirm previous results, that lines identified as highly resistant to DM in India are also resistant at locations in Africa and the Americas. Table 5 shows DM incidence in

Table 5. Mean percentage of downy mildew systemic infection in selected entries across locations[1] in the International Sorghum Downy Mildew Nursery (ISDMN) from 1976 to 1983.

	Year								
Entry	1976	1977	1978	1979	1980	1981	1982	1983	Mean
IS 18757 (QL 3)	0	0	0	0	0	0	0	0	0
Nandyal-DMRS-KHA	-[2]	-	-	-	-	0	0	0	0
IS 3443	-	-	-	-	-	0.6	0	0	0.2
IS 22227	-	-	-	-	0	0.2	0.2	1.2	0.4
IS 8185	-	-	-	-	-	0.4	0	1.5	0.6
IS 22229	-	-	-	-	0	0.7	0	1.9	0.7
IS 22228	-	-	-	-	0	0.5	0.7	1.4	0.7
IS 8283	-	-	-	-	-	0.4	1.5	1.1	1.0
IS 22230	-	-	-	-	0	3.1	0	1.4	1.1
IS 8607	-	-	-	-	-	0.6	0.6	2.3	1.2
IS 7528	-	-	-	-	-	2.3	0.5	1.6	1.5
IS 3547	-	-	-	-	-	3.3	0.4	0.6	1.4
IS 22231	-	-	-	-	12.0	0.9	1.5	1.4	4.0
UChV 1	2.3	3.6	3.1	7.2	8.1	12.4	6.8	4.9	6.1
Susceptible control									
DMS 652	50.0	78.0	56.1	87.6	73.2	55.9	69.6	69.7	67.5

1. Locations: Dharwad, Coimbatore, ICRISAT Center and Mysore (India), Samaru (Nigeria), Manfredi and Pergamino (Argentina), College Station, Texas *AS&M* University (USA).
2. Not included in nursery.

selected entries from 1976 to 1983. Of particular interest is the resistance of these lines to pathotype 3 of the pathogen recently discovered in the USA. Some sorghum lines previously resistant to DM in USA are highly susceptible to pathotype 3.

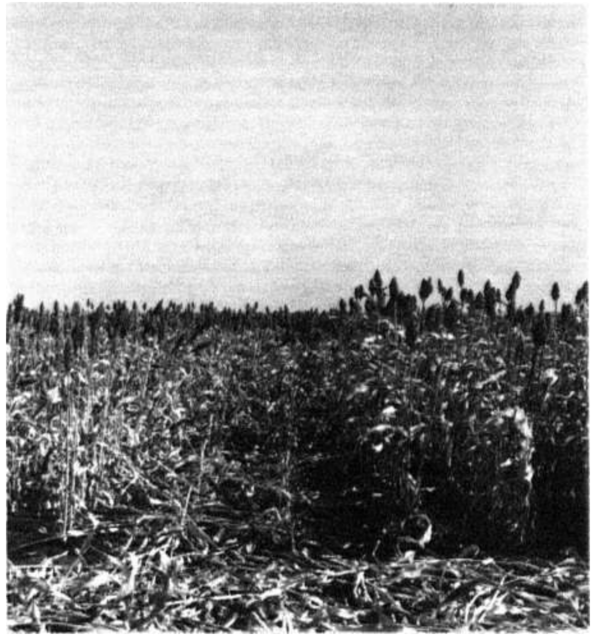
Charcoal Rot (*Macrophomina phaseolina*)

Resistance under induced drought stress. We previously reported (ICRISAT Annual Report 1982, p.32) the resistance of cultivar E 36-1 to charcoal rot under increasing stress from lack of water in the postrainy season at four locations in India. We tested the stability of this resistance under induced stress conditions in an experiment conducted on a Vertisol in the 1983/84 postrainy season at ICRISAT Center. The incidence of charcoal rot in E 36-1 was compared with that in the susceptible hybrid CSH 6, under five levels of stress, created by stopping irrigation at different growth stages after floral initiation (GS_3) in a split-split-plot design with six replications. Plant population was standard for sorghum at 133 350 plants ha^{-1}. We monitored charcoal rot development by recording lodging, root infection, stalk infection (soft stalk), and the extent of infection up the stalk from the crown (number of nodes crossed). We determined infection at physiological maturity in individual plants by isolations of *M. phaseolina* from diseased stems and roots.

Results in Table 6 clearly show the resistance of E 36-1 to charcoal rot even under the most severe stress treatment (MST_5) when the hybrid CSH 6 was highly susceptible.

Anthracnose (*Colletotrichum graminicola*)

Screening for resistance. In preliminary screening at Pantnagar, northern India (ICRISAT Annual Report 1983, pp.26-27) we evaluated 235 germplasm accessions and 1112 advanced generation breeding lines in single rows and selected 7 germplasm accessions and 208 breeding lines for further screening. In advanced screening during the rainy season, 96 entries found resistant in 1982, and 11 entries



Sorghum cultivar E 36-1 (right), showing resistance to charcoal rot and lodging under severe drought stress conditions. The susceptible line (center), has collapsed as a result of M *phaseolina* infection, ICRISAT Center, 1983/84.

resistant in 1982 and 1983 were grown in replicated trials. Only 19 entries were selected as resistant to anthracnose from these trials. Table 7 shows the selected agronomically-elite breeding lines that showed high levels of resistance to anthracnose over all 3 years of testing.

Inoculation studies. We conducted a study to determine the crop growth stage at which plants should be inoculated for maximum disease expression. We planted 5 three-row plots of two anthracnose-susceptible genotypes (IS 18442, and IS 5279) in a randomized block design with three replications at ICRISAT Center. Each plot was surrounded by tall guard borders of pearl millet to minimize interplot interference. Plants in each plot were inoculated when most plants had 5, 7, 8, and 9 fully-expanded leaves i.e., approximately 14, 21, 28, and 35 DAE. The 5th plot was not inoculated. We inoculated the plants by dropping 3-5 sorghum grains infected with C. *graminicola* into their leaf whorls. In

Table 6. Days to 50% flowering, plant height (m), leaf and plant death, lodging, soft stalk, mean number of nodes crossed, mean score for root infection and *Macrophomina phaseolina* incidence in CSH 6 and E 36-1 under five drought stress conditions, ICRISAT Center, postrainy season 1983.

Sorghum line	Drought stress treatment[1]	Days to 50% flowering	Plant height (m)	Leaf and plant death[2]	Lodging (%)	Soft stalk (%)	Mean no. nodes crossed	Mean score root infection[3]	*M. phaseolina* incidence (%)
CSH 6	MST_1	62	1.7	3.1	4.4(0.19)[4]	0	0	2.7	0
	MST_2	62	1.7	3.4	5.8 (0.23)	2.1 (0.08)	0.03	3.1	2.9(0.10)
	MST_3	62	1.7	4.7	50.1 (0.79)	59.6 (0.89)	1.75	5.0	59.6 (0.90)
	MST_4	60	1.7	4.4	49.4 (0.78)	58.3 (0.88)	1.56	5.0	58.3 (0.88)
	MST_5	60	1.6	4.8	59.9 (0.90)	69.6(1.06)	2.20	5.0	75.4(1.15)
E 36-1	MST_1	68	1.9	2.7	2.0 (0.11)	0	0[5]	2.3	0
	MST_2	68	1.9	3.0	2.2(0.13)	0	0	2.2	0
	MST_3	68	1.9	3.4	1.8(0.12)	0	0	3.0	0
	MST_4	66	1.8	3.6	5.3 (0.22)	0	0	3.0	0
	MST_5	66	1.8	3.9	7.4 (0.23)	0	0	3.0	0
SE			±0.06	±0.32	±(0.063)	±(0.065)	±0.345	±0.16	±(0.065)

1. MST_1 = Irrigation to physiological maturity
   MST_2 = irrigation to soft dough stage
   MST_3 = Irrigation to 50% flowering
   MST_4 = Irrigation to boot leaf stage
   MST_5 = Irrigation to final leaf in the whorl.
2. Leaf and plant death scores on a 1 to 5 scale, where 1 = completely green, and 5 = dead.
3. Root infection score on a 1 to 5 scale, where 0 = no discoloration or infection, and 5 = more than 50% roots showing infection and discoloration.
4. Figures in parentheses are arc sine transformed values.
5. Zero values not used in SE calculation.

Table 7. Percentage leaf area damaged (LAD) and anthracnose score (AS) of anthracnose-resistant sorghum entries[1], Pantnagar, India, rainy season 1982 to 1984.

Entry	Pedigree	Mean days to flowering[4]	Year 1982 LAD[2]	1982 AS[3]	1983 LAD	1983 AS	1984 LAD	1984 AS
M 36266	[(WABC x SC 108-3)-1-1 x IS 9327]	79	1.5	2	5.0	2	2.0	2
M 60288	[IS 12611 x (SC 108-4-8 x CS 3541)-38-1]-3-1	81	2.0	2	4.5	2	5.0	2
PYT 2 E.No.l	E 35-1 x US/R-27-1-1-2-3	80	2.0	2	5.0	2	5.0	2
PYT 2 E.No.6	CSV 4 x GG x 370-2-1-2-8	80	2.0	2	3.0	2	5.0	2
Trial 74 C-27	(Framida x 2219B)-1-5	79	2.0	2	4.0	2	4.4	2
Susceptible control								
IS 18442	H 112	67	78.0	5	85.0	5	80.0	5

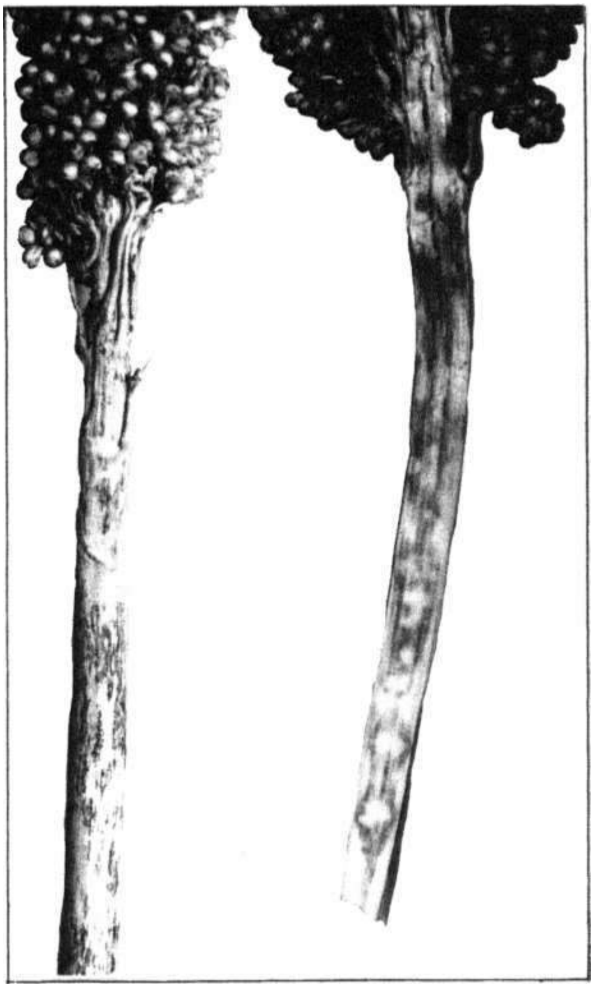
1. Resistant entries are those with anthracnose scores <2.0 (i.e., upto 5% leaf area of top four leaves damaged).
2. Percentage leaf area of top four leaves damaged at soft dough stage. Mean of 10 plants in each of two replications.
3. Rated on a 1 to 5 scale, where 1 = no anthracnose and 5 = severe anthracnose with more than 40% leaf area of top four leaves damaged.
4. From 3 years' data, 1982 to 1984.

each plot, the percentage leaf area damaged was recorded on each leaf of 10 randomly-selected plants in the central row, at 7- to 10-day intervals, until the hard dough stage when plants had 16 leaves.

Our results showed that all inoculated plants were infected by anthracnose irrespective of the plant growth stage at inoculation. The rate of disease progress was, however, faster on older leaves than on younger ones. On the top four leaves at the hard dough stage, maximum disease severity (38 to 57% leaf area damaged) was recorded on plants inoculated when nine leaves were fully expanded, moderate disease (22 to 37%) on plants with eight leaves expanded, and least disease (9 to 23%) when plants with seven leaves expanded were inoculated.

Spread of the pathogen. At ICRISAT Center, we initiated field experiments on the spread of anthracnose inoculum, in an attempt to develop a relevant field-screening technique. We inoculated with *C. graminicola* the susceptible sorghum line IS 18422 sown in a 18 m^2 plot in the middle of a 1815 m^2 field. All the plants became heavily infected, and the pathogen sporulated profusely. This patch of infected plants served as a focus, or source, of anthracnose inoculum whose spread was monitored on anthracnose-susceptible plants of IS 382 sown in the rest of the field two weeks later than IS 18422. Sprinkler irrigation was provided to the whole field on rain-free days to provide the moist environment essential for anthracnose development.

Our results showed two patterns of pathogen spread. The first, mostly in the downwind direction to the end of the field, a distance of 27 m. Here, the inoculum was probably spread by wind-driven rain during showers, or by water droplets during sprinkler irrigation, since the inoculum of *C. graminicola* occurs in a slime. The severity of anthracnose on the test plants was inversely proportional to their distance from the inoculum source. The second pattern was along the ridges down the slope from the inoculum source. This was due to inoculum in infected leaf debris being transported by running water along the furrows when it rained. We are continuing work on these two types of inoculum spread.



Sorghum panicles showing stem lesions on the peduncle (left) and internal symptoms (right) due to infection by the anthracnose pathogen, *Colletotrichum graminicola.*

Multilocational Testing for Stability of Resistance to Leaf Diseases

The 1983 International Sorghum Leaf Disease Nursery (ISLDN) consisting of 23 test entries, and 7 susceptible controls was evaluated against several leaf diseases by cooperators at: Oran-Salta and Pergamino (Argentina); Dharwad, Indore, Pantnagar, and Udaipur (India);

Samaru (Nigeria); Laguna (Philippines); and at Kadugli and Wad Medani (Sudan). All the entries except IS 18758 at Udaipur were susceptible to zonate leaf spot *(Gloeocercospora sorghi),* and to leaf blight *(Exserohilum turcicum)* at Samaru. Table 8 shows disease scores of selected entries resistant to eight or nine diseases across locations. It is noteworthy that the three resistant entries IS 18758 (E 35-1), SPV 351, and SPV 386 are high-yielding ICRISAT-bred or selected varieties that have been released by national programs for use by farmers in Burkina Faso, India, and Zambia.

Insect Pests

Sorghum Shoot Fly *(Atherigona soccata)*

Biology. We monitored shoot fly populations from 1977 to 1979 using fish-meal baited traps, and correlated our results with egg-laying incidence and deadheart formation on susceptible sorghum hybrid CSH 1, planted at monthly intervals at two locations at ICRISAT Center. We found that egg laying and deadheart formation were correlated (r = 0.73**). The total numbers of all flies caught were correlated with *Atherigona soccata* catches (r = 0.84**). Egg laying was correlated to total trap catches (r = 0.63**) and *A. soccata* catches (r = 0.67**). Deadhearts were also correlated to the total (r = 0.56**) and *A. soccata* (r = 0.58**) trap catches. Shoot fly incidence was mostly a function of the total fly population present at a time, however, environmental factors such as temperature, humidity, and rainfall influence its population and incidence. Maximum temperature was negatively correlated with fly catches, egg laying, and deadheart formation, whereas morning and evening humidity showed significant positive correlations to fly catches, egg laying, and deadheart formation.

Screening for resistance. We screened 3000 new germplasm accessions and 550 breeding lines for shoot fly resistance in the field using the interlard fishmeal technique, and selected 71 germplasm accessions and 42 breeding lines for further testing. To differentiate various resistance mechanisms, 42 lines identified as less susceptible in 1983, were tested again in a replicated field trial. Twenty lines showed around 50% less deadheart formation than the susceptible control, CSH 1 (Table 9). On ten of these lines there was 30% less oviposition than on CSH 1, while all except IS 18551 expressed a biophysical / anti-

Table 8. Maximum[1] leaf disease scores[2] across locations of selected lines in the 1983 International Sorghum Leaf Disease Nursery (ISLDN).

	Leaf disease[3] and score										
Entry[4]	A	R	LB	GLS	ZLS	SS	RLS	OLS	RSB	BLS	MDMV
IS 18758 (E 35-1)	2	3	5	1	3	1	2	1	4	2	3
IS 18484 (CS 3541)	2	3	5	2	4	1	2	1	3	3	3
SPV 351	3	2	5	5	4	3	1	1	3	2	3
SPV 386	4	3	5	3	4	1	1	1	3	1	3
SPV 387	2	2	4	2	4	1	2	1	3	2	3
M 36278	3	3	5	1	4	1	1	1	3	2	3
M 36346	3	3	5	2	4	1	1	1	3	2	3

1. Maximum score at locations where leaf diseases occurred with sufficient pressure.
2. Based on a 1 to 5 scale, where 1 = no disease and 5 = severe disease with more than 40% leaf area of top four leaves damaged.
3. Leaf diseases; anthracnose (A), rust (R), leaf blight (LB), gray leaf spot (GLS), zonate leaf spot (ZLS), sooty stripe (SS), rough leaf spot (RLS), oval leaf spot (OLS), rhizoctonia leaf and sheath blight (RSB), bacterial leaf stripe (BLS), and maize dwarf mosaic virus (MDMV).
4. Pedigrees of the last five entries in descending order are (SC 108-3 x CS 3541)-19-1, (SC 108-4-8 x C 3541)-88, [(SC 423 x CS 3541) x E 35-1]-2-1, (SC 108-3 x E 35-1)-25-1, and (CS 3541 x 2KX-6-2)-10-1.

Table 9. Reaction to shoot fly of some less-susceptible sorghum lines, ICRISAT Center, rainy season 1984.

	Shoot fly infestation			
Entry	Deadhearts (%)	Egg laying (%)	Deadhearts/ egg laying (%)	Dominant resistance mechanism[1]
IS 1034	30.9	77.1	37.6	B
IS 1104	26.3	58.8	39.6	A and B
IS 2146	36.7	58.1	47.1	A and B
IS 2195	28.3	71.5	41.6	B
IS 2205	25.9	59.2	42.2	A and B
IS 2309	28.1	58.3	45.1	A and B
IS 2312	30.1	66.2	45.6	A and B
IS 4646	33.6	64.8	51.6	A and B
IS 4664	20.0	63.6	31.8	A and B
IS 5072	31.4	94.3	33.3	B
IS 5470	36.4	72.2	51.3	B
IS 5480	22.4	57.5	40.5	A and B
IS 5538	30.6	83.0	40.2	B
IS 5566	32.2	76.9	41.2	B
IS 5613	31.7	59.3	45.2	A and B
IS 5622	34.2	71.5	48.5	B
IS 5636	31.9	84.7	37.0	B
IS 18369	33.7	70.2	44.2	B
IS 18371	29.1	76.1	39.8	B
IS 18551	33.7	44.1	57.6	A
Susceptible control				
CSH 1	74.5	94.6	77.0	
SE	±8.88	±9.20	±10.63	
CV (%)	35	21	34	

1. Dominant resistance mechanism (30% superior over CSH 1): A = Ovipositional nonpreference, B = Biophysical/antibiosis.

biosis mechanism of resistance (more than 30% superiority over CSH 1). All 42 less-susceptible lines were also tested under no choice conditions in cages during both rainy (Jul-Aug) and post-rainy (Oct-Nov) seasons. Resistant lines in both seasons were IS 1034, IS 1057, IS 2146, IS 2205, and IS 5470.

Multilocational testing. We sent 13 germplasm accessions, 10 breeding lines, and 2 control cultivars (local and CSH 1), to 20 locations (11 in India, and one each in Burkina Faso, Cameroon, Italy, Mozambique, Nigeria, Senegal, Somalia, Thailand, and Uganda) to be evaluated for resistance in the International Sorghum Shoot Fly Nursery (ISSFN). We received data from 11 locations (7 from India and one each in Burkina Faso, Ghana, Nigeria, and Thailand). Twenty lines had less than 25% shoot fly incidence compared with 49% on CSH 1 and 42% on the local control cultivar. The most promising lines were IS 2146, IS 5470, PS 14454, and PS 19794.

Breeding for resistance. We random-mated our shoot fly- and stem borer-resistant population during the rainy season under insect pest protection, and during the postrainy season under moderate natural shoot fly and stem borer

Sorghum shoot fly screening trial showing cages used to provide uniform egg infestation under no-choice conditions. Plants in foreground show deadheart symptoms as a result of earlier infestation, ICRISAT Center, 1984.

infestations. During the second random mating, shoot fly-resistant genes from improved breeding lines were incorporated into the population to further improve its agronomic features and resistance to shoot fly.

We completed conversion to male sterility of three nonrestorer, shoot fly-resistant breeding lines, PS 14832, PS21459, and PS24453. The new male-sterile lines were test-crossed to 30 improved shoot fly-resistant restorer lines during the postrainy season. The resulting experimental hybrids will be evaluated for grain yield and adaptation, and screened for shoot fly resistance during the 1985 rainy season.

We made crosses between ten improved shoot fly-resistant breeding lines and a number of elite lines during the rainy season and advanced them to F_1 generation during the postrainy season. Their F_2 segregating progenies will be screened for shoot fly resistance and agronomic desirability in 1985.

We evaluated approximately 1820 F_4 to F_6 progenies for agronomic eliteness and resistance to shoot fly during the rainy season at ICRISAT Center, and made individual selections from 705 progenies identified as less-susceptible. We also evaluated 120 less-susceptible progenies that had been screened for shoot fly resistance in previous years, and selected 60 less-susceptible lines with good agronomic traits. The best advanced progenies are PS 19349, PS 19663-3, PS 21113-1, PS21227-2, PS21239-2, PS24955-3, PS 27618-5, PS 27655-11, and PS 28060-1.

Stem Borer (*Chilo partellus*)

Population dynamics. We monitored the stem borer population at Hisar through light trap catches, and by assessing larval damage in sorghum planted at monthly intervals from April to August. Our results show that *C. partellus* is most active during August and September, and therefore, a crop sown between the 1st and 3rd weeks of July should be exposed to maximum insect pressure for resistance screening. During 1984, stem borer infestation was very heavy on sorghum sown during the 2nd week of July.

Selection criteria for resistance screening. We have found that the deadheart symptoms caused by stem borer infestation is the most important trait contributing to grain yield loss. We obtained a negative correlation (r = -0.90**) between deadhearts and grain yield in sorghum hybrid CSH 1. Stem tunneling by the borer is also important for evaluating resistance, but assessing the extent of tunneling involves the laborious process of splitting individual sorghum stems. We examined other traits such as the percentage of internodes bored, and the number of holes per plant. We found both these traits to be correlated with stem tunneling (Table 10), and can therefore be used instead of tunneling to evaluate resistance.

Yield loss assessment. We conducted a trial at Hisar to estimate grain yield loss caused by stem borers using susceptible cultivars CSH1, and ICSV 1 (SPV351), and a resistant line IS 2205. The crop was protected by applying 3% carbofuran granules in the plant whorl at various growth stages (T_1 to T_7). Deadhearts and grain yield were recorded from full protection (T_1) to no protection (T_7) in all the cultivars. Deadhearts progressively increased from T_1 to T_7 while grain yield decreased for all the three cultivars (Table 11). However, the rates of deadheart increase, and grain yield decrease in the resistant line were much slower than in the susceptible cultivars.

Stem borer-resistant sorghum line IS 2205 showing fewer deadheart symptoms than the surrounding susceptible lines after artificial infestation.

Table 10. Correlation coefficients (r) between stem borer tunneling, percentage internodes bored, and holes plant^{-1}, resulting from *Chilo partellus* infestation on sorghum at two locations in two seasons.

		Correlation coef.(r) between stem tunneling and	
Season/ location	No. of lines	internodes bored (%)	holes plant^{-1}
Postrainy 1982-83 (ICRISAT Center)	62	0.74**	0.47**
Rainy 1983 (Hisar)			
Expt.1	62	0.69**	0.75**
Expt.2	62	0.85**	0.80**
Rainy 1983 (ICRISAT Center)			
Expt.1	63	-	0.64**
Expt.2	63	-	0.83**

Table 11. Effect of various protection levels on stem borer infestation and grain yield of three sorghum cultivars, Hisar, rainy season 1984.

	ICSV 1		CSH 1		IS 2205		Mean	
Stem borer protection levels[1]	Borer incidence (%)	Grain yield (kg ha^{-1})	Borer incidence (%)	Grain yield (kg ha^{-1})	Borer incidence (%)	Grain yield (kg ha^{-1})	Borer incidence (%)	Grain yield (kg ha^{-1})
T_1	28.0	4240	25.2	5170	33.9	1870	29.1	3760
T_2	49.0	2630	23.8	4380	37.6	1280	36.8	2770
T_3	50.2	2620	39.2	4790	30.6	1910	40.0	3100
T_4	75.9	760	61.1	3110	43.2	1040	60.1	1640
T_5	79.4	740	43.7	3700	43.0	1180	55.4	1870
T_6	100.0	330	95.1	2600	47.6	900	80.9	1280
T_7	100.0	0	100.0	190	85.5	130	95.2	100
Mean	68.9	1620	55.5	3420	45.9	1180		

	Borer incidence	Grain yield
SE for comparison treatment within same cultivar	±9.18	±455
SE for comparison treatment within different cultivars	±8.47	±459
SE (cultivar)	±3.20	±173
SE (treatment)	±6.04	±257
CV(%)	18	27

1. T_1 = Carbofuran applied at 15, 30, and 45 days after emergence (DAE)
T_2 = Carbofuran applied at 15 and 30 DAE
T_3 = Carbofuran applied at 30 and 45 DAE
T_4 = Carbofuran applied at 15 DAE
T_5 = Carbofuran applied at 30 DAE
T_6 = Carbofuran applied at 45 DAE
T_7 = Control (untreated)

With no protection (T_7) all three cultivars had negligible grain yields due to severe infestation.

Screening for resistance. We screened 1700 new germplasm accessions and 468 previously-selected lines for stem borer resistance at Hisar in an unreplicated nursery, and selected 26 lines for further testing. Stability analysis of 61 previously-selected, less-susceptible lines and one susceptible hybrid (CSH 1) over six environments showed four lines, IS 5470, IS 5604, IS 8320, and IS 18573 had the most stable resistance to stem borer.

Breeding for resistance. We made crosses between stem borer-resistant lines and a number of elite lines during the 1983 postrainy season, and advanced them to F_1 in the greenhouse during the summer season. Their 19 F_2 segregating progenies were screened for stem borer resistance under artificial infestation during the rainy season at ICRISAT Center, and we selected 173 stem borer-free progenies.

We also evaluated approximately 580 F_5 and F_6 shoot fly-resistant progenies for resistance to stem borer under natural infestations at Hisar, and under artificial conditions at ICRISAT Center during the rainy season, and selected 7 less-susceptible lines; of these PS 19881-1 had the lowest stem borer infestation.

We studied gene effects on resistance to stem borer in sorghum. Our results indicated that resistance is a complex, polygenically-inherited trait. Different gene effects operate under different conditions. Epistatic gene effects were found to operate under artificial inoculation conditions, and major gene effects under conditions of natural infestation, when we also noticed cytoplasmic influences.

Sorghum Midge (*Contarinia sorghicola*)

Population monitoring. Studies on population monitoring and diapause continued at Dharwad and Bhavanisagar on sorghum lines sown at fortnightly intervals. We observed maximum midge population during November at Dharwad, and during May-June at Bhavanisagar. We also monitored the midge population at ICRISAT Center using yellow-colored traps with chemical attractants, and observed a much higher midge population during the rainy season than in previous years.

Screening for resistance. We screened 2000 germplasm lines for midge resistance, and selected 118 lines for further testing. Twenty-six selected germplasm and breeding lines showed consistently high levels of resistance under natural infestation and headcage testing at Dharwad and ICRISAT Center, and under natural conditions at Hisar.

We screened 21 advanced cultivars for midge resistance under no-choice (headcage), and natural conditions for four seasons at ICRISAT Center (Table 12). Eleven cultivars suffered less

Table 12. Sorghum cultivars showing midge infestation under no-choice conditions over four seasons, ICRISAT Center.

	Florets with midge larvae (%)				Chaffy florets (%)			
Cultivar	1980 R[1]	1980/81P[2]	1981R	1981/82P	1980R	1980/81P	1981 R	1981/82P
DJ 6514	21.0	11.5	18.5	2.3	60.0	20.0	36.5	19.0
TAM 2566	16.0	16.0	25.0	18.7	21.0	53.3	38.0	27.0
IS 12666C	33.0	20.0	30.5	24.3	52.5	36.5	73.0	35.0
IS 12573C	16.0	46.5	17.0	36.3	55.5	80.0	55.5	63.0
IS 2579C	27.5	45.5	34.0	53.7	70.0	72.5	74.0	64.7
IS 12664C	30.5	30.5	46.5	55.0	33.0	41.5	86.0	63.0
IS 1151	22.5	35.0	45.0	66.3	51.5	60.5	91.0	79.3
IS 12612C	26.0	48.0	57.0	39.3	48.5	44.5	65.0	60.3
EC 92792	40.0	29.5	60.0	42.7	33.5	57.5	66.5	59.7
IS 12611	31.5	36.0	56.0	61.0	48.0	54.0	74.0	71.7
S GIRL-MR 1	34.0	44.5	64.0	45.3	57.0	57.0	80.0	64.3
IS 2327	46.0	51.0	54.0	46.0	32.0	69.0	76.5	59.0
IS 1510	36.0	45.0	55.0	70.3	80.0	55.0	83.5	84.7
EC 92793	43.0	38.0	70.5	56.7	52.0	55.0	79.0	66.0
ENTM 3	48.5	57.0	45.0	58.3	71.0	50.0	77.5	72.7
IS 12608C	36.0	45.5	71.0	58.3	35.5	80.0	94.0	70.3
IS 2328	67.0	62.0	24.0	58.3	63.0	70.5	93.0	67.7
EC 92794	47.0	45.5	69.5	51.7	54.0	54.5	83.0	75.0
IS 2816C	42.5	71.5	42.5	66.0	25.0	83.0	25.0	79.0
IS 6195	70.0	37.5	70.0	54.3	59.0	56.0	58.5	86.7
CSH 1	58.0	54.0	57.0	71.0	71.0	69.0	81.5	80.3
SE	±8.72	±9.13	±6.65	±9.22	±12.97	±10.40	±9.08	±8.29
CV (%)	32	31	19	26	36	25	18	18

1. R = rainy season.
2. P = postrainy season.

than 12% midge damage under natural conditions. Three cultivars, DJ 6514, TAM 2566, and IS 12666C showed repeatable and stable levels of resistance over all four seasons under no-choice conditions. TAM 2566 and IS 12666C also showed anti-xenotic resistance (nonpreference) under field conditions.

Breeding for resistance. We incorporated 12 improved midge-resistant breeding lines into our panicle-feeding (midge and head bugs) pest-resistant population during 1983/84 postrainy season at ICRISAT Center. In the following rainy season, the population was random-mated under moderate natural midge infestation at Dharwad.

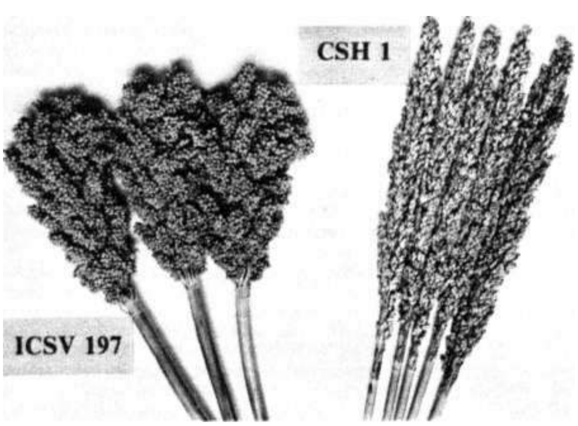
We identified improved, midge-resistant lines PM 7068, PM 7407, and PM 11808 as nonrestorers and initiated a backcrossing program to convert them into male-sterile lines. Midge-resistant nonrestorers, PM 7060, PM 7061, and PM 6751 identified earlier are in the BC_2 stage of conversion.

We made crosses between 12 improved midge-resistant breeding lines and 29 elite lines during the 1983 postrainy season and advanced them to F_1 generation during the following summer season in the greenhouse. The resulting 145 F_2 segregating progenies were screened for midge resistance and agronomic desirability at Dharwad during the rainy season, and we made 625 midge-free individual plant selections. Of those, 113 selections were from crosses involving ICSV 197 (PM 11344), an improved midge-resistant line. We also evaluated approximately 225 F_4 to F_6 progenies for resistance to midge during the rainy season at Dharwad, and identified 208 agronomically-promising, midge-free individual plants from less-susceptible progenies (Table 13).

We evaluated 130 advanced progenies for midge resistance at Pantnagar during the 1984 rainy season. Seventy-four of them were free from midge damage.

The best advanced midge-resistant lines across locations were PM6978, PM 7018, PM7138, PM7147-1, PM7177, PM7321, PM 7568, PM 7574, ICSV 197, PM 7318-2, PM 7526, PM 10825-1, and PM 7322. Table 13 shows the performance data of the three best lines at ICRISAT Center and Dharwad. We also evaluated ICSV 197, a midge-resistant improved breeding line for resistance to midge at four locations: ICRISAT Center, Dharwad, Pantnagar, and Tolichowki. The results obtained showed that the midge resistance was maintained at all locations.

Panicles of improved sorghum variety ICSV 197 (left) that has good agronomic traits and resistance to midge, *Contarinia sorghicola,* across locations compared with susceptible hybrid CSH 1 (right).



Head Bug (*Calocoris angustatus*)

Biology. Our monitoring of head bug populations at ICRISAT Center indicated peak activity during September. Head bugs were observed to be active in farmers' fields on off-season fodder sorghum during the summer season.

Chemical control. We tested several insecticides for head bug control during the 1982 and 1983 rainy seasons, and 1982/83 postrainy season at ICRISAT Center, Carbaryl (0.1%) was the most effective, followed by fenvalerate (0.01%), chlorpyriphos (0.05%), quinalphos (0.05%), and malathion (0.05%) (Table 14). Carbaryl (0.1%) was most effective when applied at post-anthesis and milky-grain stages. Dichlorvos and fenitrothion were phytotoxic to leaves.

Table 13. Performance of selected midge-resistant sorghum breeding lines at ICRISAT Center and Dharwad, rainy season 1984.

Line	Pedigree	Days to 50% flowering	Grain yield (kg ha^{-1}) Site A[1]	Site B[2]	Seed set (%)
ICSV 197 (PM 11344)	(IS 3443 x DJ6514)-1-1-1-1	66	5840	3810	90
PM 7322	(IS 12573C x SC 108-4-8KM-3-1	54	5220	3260	81
PM 7400-1-3	(IS 2579C x DJ 6514)-15-1-1-1	62	4840	2920	77
Controls					
CSH 1		48	3940	1520	26
DJ 6514		73	3910	2310	64
SE		±0.8	±427	±447	
CV (%)		1.3	10	19	

1. Evaluated under high fertility and insect control at ICRISAT Center.
2. Evaluated under high fertility and natural midge infestation at Dharwad.

Screening for resistance. Four infester rows of a susceptible cultivar (CSH 1) were planted 20 days earlier than the test material. The infester rows were planted after every 16 rows. At the time of head emergence in the infester rows, head bugs collected from other fields were uniformly spread in the infester rows.

The head bug population built up for one generation on the infester rows and then moved to the test material. We used this infestor-row technique to screen 3856 sorghum germplasm lines for head bug resistance, and selected 113 lines for further testing.

We screened 12 less-susceptible and 3 susceptible cultivars under headcages during the 1983 rainy season. At emergence the heads were infested with 5 or 15 pairs of head bugs. The results are shown in Table 15. Eight cultivars had significantly fewer head bugs 20 days after infestation with 15 pairs per head. Cultivars 1S4544,

Table 14. Insecticides tested for head bug control on susceptible sorghum hybrid CSH 1, ICRISAT Center, rainy season 1983.

Insecticide	Number of head bugs $head^{-1}$ Postanthesis Before spray	Postanthesis 24 h after spray	Milky stage Before spray	Milky stage 24 h after spray	Grain yield (kg ha^{-1})	1000-grain mass (g)
Carbaryl	13 (3.3V	1 (1.4)	18 (4.2)	1.5(1.2)	2400	27.8
Fenvalerate	8 (2.6)	1 (1.4)	26 (5.0)	5 (2.3)	2370	27.0
Chlorpyriphos	13 (3.3)	5 (2.3)	16 (2.9)	19 (3.9)	2340	24.7
Quinalphos	9 (2.8)	2(1.5)	19 (4.1)	5 (1.8)	2040	27.1
Malathion	11 (2.6)	2(1.6)	19 (4.2)	7 (2.4)	2020	24.3
Untreated control	9(2.4)	1 (1.4)	26 (4.9)	54 (7.3)	1800	23.3
SE	(±0.74)	(±0.30)	(±0.44)	(±0.52)	±312	±1.33

1. Figures in parentheses are square root transformed values.

Table 15. Population increase and grain damage in 15 sorghum cultivars infested with 5 and 15 pairs of head bugs panicle[1], ICRISAT Center, rainy season 1983.

Cultivar	Head bugs panicle^{-1}		Damage rating[1]		Germination (%)	
	5 pairs	15 pairs	5 pairs	15 pairs	5 pairs	15 pairs
IS 17610	104 (10.1)2	84 (9.0)[2]	3.3	3.0	72 (57.8)3	85 (67.0)[3]
IS 17645	83 (8.9)	174(13.2)	3.0	3.2	74 (59.7)	84 (66.7)
IS 9639	25 (4.3)	204 (14.2)	3.0	3.9	78 (62.2)	80 (63.7)
IS 17618	132(11.5)	312(17.7)	3.5	3.5	83 (65.3)	76 (60.8)
IS 4544	119(10.8)	374(19.3)	2.3	3.2	70 (57.9)	72 (57.7)
IS 9692	83 (8.9)	232(15.2)	4.2	4.7	67 (54.9)	66 (54.0)
IS 14476	47 (6.8)	63 (7.9)	4.2	5.0	64 (52.8)	46 (42.4)
IS 21217	88 (9.3)	297(17.1)	3.8	4.7	64(53.1)	42 (39.8)
IS 6983	34 (5.8)	57 (7.1)	4.1	4.0	71 (57.5)	42 (40.2)
IS 2761	44 (6.6)	204 (14.3)	3.9	4.3	86 (68.1)	37 (37.2)
IS 6984	123(11.0)	50 (7.0)	4.8	5.0	57 (48.8)	30 (32.9)
CSH 5	178 (13.3)	394 (19.8)	4.1	3.7	4 (10.5)	12(19.8)
CSH 1	281 (16.7)	625 (25.0)	4.5	4.6	37 (37.3)	6 (13.6)
CSH 9	279 (16.7)	495 (22.2)	4.4	4.9	9 (17.4)	3 (8.6)
Swarna	226(15.0)	277 (16.6)	5.0	5.0	7(13.7)	0.1 (1.8)
SE	±(0.83)		±0.06		±(4.60)	

1. Damage rating on a 1 to 5 scale, where 1 = few feeding punctures on the grain and 5 = grains undeveloped, heads chaffy.
2. Figures in parentheses are square root transformed values.
3. Figures in parentheses are arc sine transformed values.

IS 17645, IS 17618, and IS 17610 suffered moderate grain damage (rating 3 to 3.5) while IS4544, IS9639, IS 17618, IS 17610, and IS 17645 had germination rates over 70% compared to 12% or less in the susceptible cultivars CSH 1, CSH 5, CSH 9, and Swarna.

Oriental Armyworm (*Mythimna separata*)

Biology. We monitored the armyworm population at ICRISAT Center using light traps throughout the year. The population started to increase in August, peaked in September, and declined from October to November. Trap catches in 1984 were much lower than those recorded in the previous 5 years, probably because the rainfall was low and erratic.

Screening for resistance. We screened 600 sorghum germplasm lines, selected as less susceptible under field conditions in 1983, for leaf damage under greenhouse conditions, and selected 50 lines for further testing. We also evaluated ten lines for armyworm damage in large plots (108 m^2) under field conditions and found IS 9692, IS 61, IS 6984, CSH5, and CSH9 had 10-20% leaf area damaged compared to a susceptible line IS 2761, that had more than 40% of its leaf area damaged. In general tall, fast-growing cultivars with long internodes suffered less damage 40 DAE under field conditions than short, slow-growing cultivars.

Neem *(Azadirachta indica)* for Insect Control

Laboratory testing. In collaboration with the Regional Research Laboratories (RRL), Hyderabad, India, and Justus Liebig University (JLU), Giessen, Federal Republic of Germany, we continued to study the antifeedant properties of neem (*Azadirachta indica).* We investigated the dosage antifeedant response of neem extract (fraction G) using 3rd instar larvae of *Mythimna separata.* Fraction G is an active antifeedant, reducing leaf feeding by about 50% at concentrations as low as 0.005%. At concentrations of 0.04%, feeding was completely inhibited under laboratory conditions.

A number of formulations were made from fraction G using different solvents and synergists, and Emulgator WR as an emulsifier, and tested at 0.05% concentration. We found on visually assessing the leaf damage caused, the formulation with fraction G in methanol + piperonyl butoxide (PBO) was the most active under laboratory conditions (Table 16). PBO synergized the action of fraction G in both methanol and benzyl alcohol.

Table 16. Effect of four neem fraction G formulations on leaf feeding and larval mass of 3rd instar larvae of *Mythimna separata* under laboratory conditions, ICRISAT Center, 1984.

Formulation	Damage rating[1]	Larval mass(g)
Fraction G in benzyl alcohol + piperonyl butoxide	3.0	0.16
Fraction G in benzyl alcohol	4.0	0.52
Fraction G in methanol + piperonyl butoxide	1.5	0.20
Fraction G in methanol	3.2	0.30
Piperonyl butoxide	2.3	0.16
Emulsifier	4.0	0.53
Untreated control	4.5	0.89
SE	±0.38	±0.110

1. Based on a 1 to 5 scale, where 1 = 10%, 2 = 11-25%, 3 = 26-40%, 4 = 41-60%, and 5 = >60% leaf area consumed.

Field testing. We evaluated an enriched neem extract from JLU for pest control on sorghum CSH 1 under field conditions. The insect numbers recorded, and damage caused by gray weevil *(Myllocerus* sp), oriental armyworm *(Mythimna separata),* and stem borer *(Chilo partellus)* in treated plots were significantly reduced compared to untreated plots. Plots sprayed with neem extract yielded almost twice as much grain as untreated plots (Table 17).

Microbial Associations

Biological Nitrogen Fixation

Nitrogen balance studies. In a long-term, nitrogen-balance field trial started in 1978, eight sorghum cultivars (Table 18) are grown each year on the same plot with the same rates of added nitrogen. However, due to continued cropping with sorghum, the subsequent sorghum crops grew poorly. To overcome such problems during the 7th year of the experiment (rainy season 1984), a uniform crop of millet cultivar ICMV 1 was grown with the same levels

Table 17. Effect of neem extract on insect pests and grain yield of sorghum cultivar CSH 1 under field conditions, ICR1SAT Center, rainy season 1983.

Treatment	Gray weevils/ 100 plants	Armyworm damage	Stem borer damage: Internodes bored (%)	Stem borer damage: Stem tunneling (%)	Head bugs/ 10 heads	Grain yield (kg ha^{-1})
Neem extract	18 (4.3)[1]	2.7[2]	5.6 (13.3)[3]	3.6 (10.2)3	389 (19)[1]	2250
Emulsifier	41 (6.3)	3.5	19.7(26.1)	12.3 (20.3)	585(24)	1083
Untreated control	31 (5.5)	3.8	17.7 (24.6)	13.7(21.5)	661 (25)	1167
SE	± (0.34)		±(1.93)	±(1.74)	±(1.5)	±183

1. Numbers in parentheses are square root transformed values.
2. Damage rating based on a 1 to 5 scale, where 1 = 10%, 2 = 11-25%, 3 = 26-40%, 4 = 41-60%, and 5 = >60% leaf area consumed.
3. Numbers in parentheses are arc sine transformed values.

Table 18. Total dry-matter yield (kg ha^{-1}) of millet cultivar ICMV 1 grown in plots previously cropped with sorghum cultivars in long-term nitrogen-balance trial, ICRISAT Center, rainy season 1984[1].

Sorghum cultivar grown in previous years	Nitrogen fertilizer applied (kg ha^{-1}) 0	20	40	Mean
FLR 101	3870	5290	6290	5150
CSV 5	3750	4780	5790	4770
CSH 5	3520	5090	5640	4750
IS 2333	3530	4850	5980	4780
IS 889	4330	5620	5650	4200
Dobbs	3800	4260	5660	4570
IS 15165	4990	4840	5730	5190
Diallel 642	4280	4920	5800	5000
SE		±358		±108
Mean	4010	4960	5820	
SE		±244		
CV (%)		11		

1. Mean of four replications. Net plot area harvested = 26.25 m^2.

of added nitrogen. The total dry-matter yields of ICMV 1 varied significantly (P=<0.01) between plots previously sown with sorghum across the nitrogen levels, and amongst the nitrogen levels across the plots previously sown with sorghum. Plots previously sown with sorghum cultivar IS 889 yielded 5200 kg ha^{-1}, the maximum total dry matter across all nitrogen levels. IS 15165 had the maximum total dry-matter yield (4990 kg ha^{-1}) with no nitrogen in any year. The total dry-matter yield of millet cultivar ICMV 1 from plots where previously cultivars CSH 5 and IS 2333 were grown across the nitrogen levels were similar (Table 18). The cumulative nitrogen uptake through above-ground plant parts from 1978 to 1983 (except 1981) indicated that CSH 5 had the highest nitrogen uptake (230 kg ha^{-1}) amongst the sorghum cultivars across the applied nitrogen levels, and IS 2333 the lowest (180 kg ha^{-1}). These results suggest that sorghum cultivars vary in nitrogen-fixing ability.

Response to inoculation with nitrogen-fixing bacteria. We conducted a field trial with three sorghum cultivars, CSH 5, CSH 9, and ICSV 1, and 10 inoculation treatments using nine different strains of bacteria, during the 1984 rainy season. Inoculation resulted in increased grain yield over the noninoculated control across all cultivars. Increases varied from 2 to 10%, with maximum increases following inoculation with *Azospirillum lipoferum* (ICM 1001) and *Azospirillum* sp (ICM 101) (Table 19). A similar trend was also observed in total dry-matter production by the three cultivars.

Table 19. Grain yield (kg ha^{-1}) of sorghum cultivars inoculated with various strains of nitrogen-fixing bacteria, ICRISAT Center, rainy season 1984.

Bacterial strain	Cultivars CSH 5	CSH 9	ICSV 1	Mean[1]
Azospirillum lipoferum (ICM 1001)	4230	4140	3540	3970
Azotobacter chroococcum (ICM 2001)	3890	4120	2960	3660
NBR E[2]	3800	3820	3420	3680
A. brasilense (SL 33)[3]	4340	4040	3410	3930
Azospirillum sp (ICM 101)	4180	3980	3680	3950
Azospirillum sp (ICM 102)	4110	3830	3340	3760
Azospirillum sp (ICM 103)	4070	4040	2900	3670
Azospirillum sp (ICM 104)	4190	3850	3180	3740
A. lipoferum (4 ABL)[4]	4310	3810	3570	3890
Noninoculated control	3750	3880	3190	3610
SE		±220		±130
Mean	4090	3950	3320	
SE		±44		
CV (%)		10		

1. Mean of four replications. Net plot area harvested = 9 m^2. A basal fertilizer dose of 20 kg N and 9 kg P ha^{-1} was applied. Each plot was inoculated twice with 2.5 L liquid inoculum prepared by suspending a 70 g peat culture with viable bacterial count of $10^8 g^{-1}$ peat in 70 L water.
2. Napier Bajra Root Extract.
3. Culture obtained from the University of Alberta, Edmonton, Canada.
4. Culture obtained from Centre National de Recherche Scientifique (CNRS), France.

Effect of different levels and time of application of bacterial inoculum on grain yield. We conducted a field inoculation trial using cultivar CSH 5 during the rainy season to study the effects of different cell concentrations of *A. lipoferum* (ICM 1001), and time of applications on grain and plant dry-matter yields. The grain yield results indicated that inoculation with a peat culture suspension at sowing maximized grain yield, and that inoculation at thinning (3 weeks after sowing) also increased grain yield over the control, but the increase was substantially lower than that from plants inoculated at sowing. We observed maximum grain yield (3860 kg ha^{-1}) from a treatment where a broth culture with 10^8 bacterial cells mL^{-1} was applied at the time of sowing. But, when the bacterial cell concentration was decreased, grain yield also decreased. There was no additional benefit over single inoculation with a culture broth containing 10^3 cells mL^{-1} in a second inoculation using a culture broth with the same cell concentration.

Mycorrhiza

Genotype-dependent differences. Thirty germplasm accessions tested at two locations (ICRISAT Center and Bhavanisagar) for differences in the extent of root colonization by vesicular-arbuscular mycorrhiza (VAM) differed significantly (P = 0.05) (Table 20). The percentage colonization ranged from 15 to 18% at ICRISAT Center and 14 to 53% at Bhavanisagar. Interaction between genotype and location was highly significant (P = 0.01) suggesting VAM fungal preferences for plant type.

Rock Phosphate and VAM

In a pot trial using nonsterilized field soil containing native VAM flora, plants VAM-inoculated with *Acaulospora* sp yielded significantly (P < 0.05) more dry matter than noninoculated controls. Kodjari rock phosphate was added at levels ranging from 0 to 80 kg P ha^{-1}. Mycorrhizal inoculation plus rock phosphate at 4 kg P ha^{-1} increased dry matter by 68% over controls having only rock phosphate, and

Table 20. Mycorrhizal colonization of sorghum genotypes grown at ICRISAT Center and Bhavanisagar, rainy season 1984.

		VAM colonization (%)[1].		
Genotype	Origin (country)	ICRISAT Center	Bhavanisagar	Mean
IS 2046	USA	23	17	20
IS 8248	Uganda	19	21	20
IS 4042	India	26	20	23
IS 18345	India	18	28	23
IS 2873	Egypt	28	19	24
IS 19078	Sudan	16	34	25
IS 1052	India	37	14	26
IS 9508	S. Africa	19	32	26
IS 18309	Niger	23	29	26
IS 10747	Chad	18	35	27
IS 23502	Ethiopia	21	33	27
IS 22471	Sudan	30	24	27
IS 1024	India	24	32	28
IS 8571	Tanzania	32	25	29
IS 18415	India	26	32	29
IS 8064	Japan	15	45	30
IS 4599	India	21	41	31
IS 271	Unknown	27	37	32
IS 10755	Chad	29	37	33
IS 4001	India	28	39	34
IS 84	Egypt	48	20	34
IS 9468	S. Africa	28	41	35
IS 1035	India	37	33	35
IS 2803	Zimbabwe	32	39	36
IS 7270	Nigeria	35	38	37
IS 18440	India	41	34	38
IS 22381	Sudan	38	39	39
IS 15184	Cameroon	26	53	40
IS 2293	Sudan	46	38	42
IS 9284	Sudan	34	51	43
Control				
CSH 5	India	26	37	31
SE (genotypes)		±5.5	±5.5	±4.2
Mean		28	33	
SE (location)			±1.0	
CV (%)		27	24	

1. Values are means of eight plants from two replicate plots each with two rows, 3 m long.

the response decreased as rock phosphate application increased. These results underline the importance of mycorrhizae in the utilization of low concentrations of sparingly-soluble rock phosphate in the soil, Mycorrhizal fungi seem to vary in their efficiency to utilize rock phosphate. In a pot trial using rock phosphate (12 kg ha^{-1}) applied to a sterilized Alfisol (0.1 ppm Olsen P), 10 VAM inoculants significantly (P <0.01) increased total dry matter (TDM) and phosphorus uptake by sorghum plants. The most efficient VAM fungus, *Acaulospora* sp, increased phosphorus absorption nearly four times over *Glomus caledonius,* the least efficient VAM fungus tested.

Screening for P uptake and translocation. We developed a technique to collect 'bleeding sap' (Fig. 4) in order to monitor phosphorus translocation into the shoot, having previously found this technique feasible (ICRISAT Annual Report 1982, p.47). Sap analysis showed that phosphorus is translocated in both bound and free inorganic forms.

In a pot trial with *Acaulospora* sp, *Gigaspora calospora,* and *G. margarita,* the total mycorrhizal length was directly correlated (r = 0.86*) to free inorganic phosphorus in the bleeding sap collected from 56-day old seedlings. In a field trial with *Glomus mosseae, Gigaspora margarita,* and *G. calospora,* we found a correlation (r = 0.86*) between total phosphorus obtained by hydrolyzing the sap with acid, and total phosphorus uptake by seedlings. Positive relationships between mycorrhizal colonization, and/or total phosphorus uptake by plants indicate that the technique could be used to screen host plants and VAM fungi for P uptake. However, plant age, P source, etc. are factors that should also be considered.

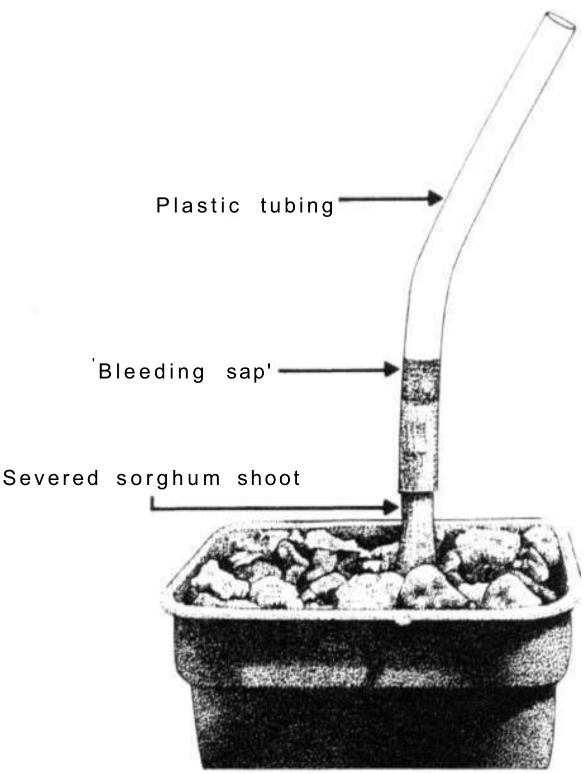


Figure 4. Seedling of sorghum cultivar CSH 5 with shoot severed to collect 'bleeding sap'. This technique is used to monitor phosphorus translocation from soil to shoot.

Plant Improvement

Multifactor Resistant Populations

We have successfully used recurrent selection breeding methods and significantly improved sorghum populations for grain yield and agronomic desirability. We have now embarked on a long-term population improvement program aimed at compositing five broadbased multifactor-resistant populations (Table 21), We will incorporate into the population, improved sources of resistance to diseases and insect pests as well as other desirable characteristics important in priority geographical regions of the semi-arid tropics (SAT). The populations when formed will be steadily improved by recurrent selection methods, and additional improved source material will be incorporated as and when they become available.

Population evaluation. A trial consisting of four cycles of selection for each of five populations was conducted in 1983 at locations in India and Africa. The results from three Indian locations have already been reported (ICRISAT

Table 21. Planned multifactor-resistant (MFR) sorghum populations.

Designation	Important trait and trait complexes to be incorporated	Monitored traits
ICSP 1 R/MFR ICSP 2 B/MFR	Resistances to grain mold, stem borer/ shoot fly, and midge	Improved grain yield, charcoal rot, stand establishment, *Striga,* and food quality
ICSP 3 R/MFR ICSP 4 B/MFR	Resistances to grain mold, stand establishment, and *Striga*	Improved grain yield, charcoal rot, stem borer/ shoot fly, midge, and food quality
ICSP 5 BR/ MFR	Improved grain yield and resistances to stem borer/shoot fly, *Striga,* and food quality	Charcoal rot, grain mold, midge, and stand establishment

Annual Report 1983, p. 39). We received and analyzed additional data from two African locations, Golden Valley Research Station, Zambia and Rattray Arnold Research Station, Zimbabwe. Selection gains over cycles for grain yield among the four populations (US/R, US/B, Rs/R, and Rs/B) were low and ranged from -17.0 to 5.9% (Table 22). It is important to note

Table 22. Grain yield (kg ha^{-1}) of different cycles and percentage gain $cycle^{-1}$ of sorghum populations evaluated at Golden Valley Research Station, Zambia[1], and Rattray Arnold Research Station, Zimbabwe[1], rainy season 1983.

Population	Cycle	Zambia	Zimbabwe	Mean	Gain (%) Per cycle	Gain (%) Overall
US/R	C_0	3060	3940	3500		
	C_1	3130	4420	3770	7.7	
	C_3	3650	5960	4800	13.7	
	C_4	2870	4030	3450	-28.1	-1.4
US/B	C_0	1890	4170	3030		
	C_2	3800	5310	4550	25.1	
	C_3	4440	4250	4350	-4.4	
	C_4	3410	3020	3210	-26.2	5.9
Rs/R	C_0	3020	5860	4440		
	C_2	3310	5440	4380	-1.4	
	C_4	3310	3790	3550	-9.5	
	C_5	4200	5170	4690	32.1	5.6
Rs/B	C_0	3680	5680	4680		
	C_2	2930	4530	3730	-10.1	
	C_4	4430	2640	3530	-2.7	
	C_5	4100	3670	3880	9.9	-17.1
WAE	C_0	1910	1810	1860		
	C_1	3090	4280	3690	98.4	
	C_2	4800	5180	4990	35.2	168.1
Control						
CSH5		3570	4570	4070		
SE		±365	±461			
CV (%)		18	18			

1. Randomized block design (RBD), plot size 18 m^2 in Zambia and 6 m^2 in Zimbabwe.

that selection gains over cycles for grain yield for the same populations at Indian locations were relatively high, ranging from 7.1 to 28%. All the populations were improved for grain yield under Indian conditions and this may partly explain why selection gains are higher at Indian than at African locations. We need to conduct more evaluation trials of these populations at many more locations in Africa and India to confirm this finding.

Development of synthetic varieties. We continued our plans to develop synthetic varieties using the most advanced populations of US/R and WAE (ICRISAT Annual Report 1983, p. 39). The six synthetic varieties under development were separately random mated twice. We will evaluate these synthetic varieties in multinational trials in India during the 1985 rainy season to estimate their stability and adaptation compared with commercial varieties and hybrids.

Derived lines. We continued pedigree selection in our most improved populations. A total of 419 derived lines in advanced generations were grown and reselected during the rainy season. All the selected lines are being advanced to the next generation during the postrainy season, and will be yield-tested in the 1985 rainy season.

In an advanced varietal trial consisting of 42 advanced population derivatives at ICRISAT Center, Dharwad, and Bhavanisagar during the 1984 rainy season, seven lines with good yield potential, and other desirable agronomic traits were selected. Those lines, ICSV163, ICSV138, ICSV 104, (FLR274 x CSV4)-6-2-1, [(FLR 141 x CSV4)-1-2 x Ind-Syn]-3-3-4, [(FLR 101 x IS 1082)-4-5-1 x Ind-Syn]-235-3-2-2, and [(SC 108 x Diallel Poll)-2-1-2-3-3], have mean grain yields ranging from 4356 to 4552 kg ha^{-1} compared to 4292 for the best control variety, ICSV 1.

Evaluating Advanced Elite Varieties

We yield-tested our 60 advanced elite sorghum varieties at three locations in India during the rainy season. These lines, derived from crosses involving recently-collected sorghum germplasm accessions have excellent grain quality characteristics. Mean grain yields of the most promising entries are presented in Table 23. Most of the selected lines possess highly corneous grains, and those derived from crosses involving IS319614, PC629, and IS 17797 also have long panicles. We also present in Tables 24 and 25 mean grain yields of several other advanced lines selected from various trials on the basis of their good yield potential and desirable agronomic traits. Most of the improved varieties will be distributed to our cooperators in the SAT for use in their breeding programs, and for multilocational evaluation.

Female Parents for Hybrids (Male Steriles)

Milo cytoplasm. We evaluated in a replicated nursery 215 A and B lines at seven locations in India during the rainy season. They were also screened for resistance to leaf diseases at Pantnagar, and to DM at Dharwad. From these, we selected 45 A and B lines of diverse origin with superior agronomic characteristics and stable performance. The mean grain yield of B lines of the selected male steriles ranged from 2500 to 4490 kg ha^{-1} compared with 3000 to 3800 kg ha^{-1} for the best commercial controls. Some of the selected lines are less susceptible to diseases and have good grain quality characteristics. In another trial, we evaluated several new male steriles derived from populations at three locations in India. The results from the most promising B lines are presented in Table 26. We will evaluate all selected male steriles for their combining ability during the 1985 rainy season.

Nonmilo cytoplasm. All the nonmilo cytoplasmic male-sterile lines we have collected (ICRISAT Annual Report 1983, p. 43, Table 21) were grown during the 1984 rainy season at three locations in India, where they all uniformly showed sterility.

Our efforts to identify fertility restorers for the nonmilo male steriles are continuing. We made several crosses between nonmilo male steriles

Table 23. Mean grain yield (kg ha^{-1}) of promising elite sorghum varieties evaluated at three locations in India, rainy season 1984.

Entry	Pedigree	ICRISAT Center	Dharwad	Bhavani-sagar	Mean
ICSV 202	[(SC 108-3 x CS 3541)-3 x ICSV 112]-2-2	5970	7220	4180	5790
M 10968	[ICSV 112 x (IS 12611 x SC 108-3)]-2	5750	6200	4880	5610
M 11026	[IS 20509 x (IS 12611 x SC 108-3)]-4-4	5530	5760	5330	5540
M 11036	[(SC 108-3 x CS 3541)-51-1-1 x (CK 60B x IS 84)]-1-1	5330	5630	5160	5370
ICSV 199	IS 1961 x [(148 x E 35-1) x CS 3541] -10-1	6220	5330	4280	5280
M 11049	[(148 x E 35-1)-2-4 x PC 629]-2-1	4720	4830	3690	4410
ICSV 200	[(148 x E 35-1)-2-4 x IS 17797]-1-2	5030	4260	3390	4230
Controls					
ICSV 2 (SPV 386)		6030	6670	3860	5520
ICSV 1 (SPV 351)		5500	5670	3930	5030
SE		±770	±970	±770	
CV(%)		14	18	19	
M 11033	[(SC 108-3 x CS 3541)-3 x ICSV 1123-2-3-1	6690	5330	3580	5200
M 11010	[IS 19614 x (is 12611 x SC 108-3)]-1-1-6-2	6610	4720	3610	4980
M 10997	[ICSV 112 x (IS 12611 x SC 108-3)]-4-4-8-27	5360	4800	3150	4440
M 11109	(E 36-1 x CS 3541)-3-15-2	5640	4350	2080	4020
Controls					
ICSV 112 (SPV 475)		5390	4350	3840	4530
ICSV 158 (SPV 615)		5190	5330	2590	4370
SE		±633	±551	±660	
CV(%)		12	12	21	

and germplasm accessions during the 1984 postrainy season. All the resulting F_1s will be grown and observed, to see whether any germplasm accessions restored fertility to any of the non-milo male steriles in the F_1 generation.

Hybrid Evaluation

We evaluated several preliminary hybrids produced from our new male-sterile lines MA 6, MA 9, MA 10, MA 12, SPL 180A, SPL 204A, and SPL 117A in replicated yield trials at three locations in India. Mean grain yields of the most productive hybrids are presented in Tables 27 and 28. All the selected hybrids that combine high yield potential with desirable agronomic traits, and good grain quality will be distributed to our cooperators in the SAT for multilocational evaluation. We will also distribute all the parents of these hybrids to interested cooperating breeders for use in their programs.

Inheritance Studies

Grain Mass and Hardness

We made a diallel cross of six sorghum lines varying in 100-grain mass and grain hardness, and evaluated the F_1 crosses and parents during the 1984 postrainy season at ICRISAT Center (irrigated), and Bijapur (on residual soil moisture). For each entry, we recorded 100-grain

Table 24. Mean grain yields (kg ha^{-1}) of selected advanced sorghum varieties evaluated[1] at three locations in India, rainy season 1984.

Entry	Pedigree	ICRISAT Center		Dharwad	Bhavani-sagar	Mean
		HF[1]	LF[3]			
DKV 1	(SPV 105 x CSV 1)-1-1-4-1	4160	3790	3560	1020	3130
DKV 73	[(M 35-1 x M I009)-3-2-1 x F_5-6]-5-2-3-1	2930	3540	4100	1640	3050
DKV 74	[(M 35-1 x M 1009)-3-2-1 x F_5-6]5-2-3-2	2040	3760	4910	1480	3050
DKV 23	(2077B x SPV 86)-2-2-2	3600	3360	4040	1100	3020
DKV 43	(22-40 x SPV 105)-6-12-1-1-1	4140	3510	2910	1170	2930
DKV 19	(DH 531-77R x E 185-2)-9-2-1-1-1	3410	3560	3590	1350	2930
DKV 3	(20-67 x SB 1067)-4-1-1-1-1	4010	2950	3880	780	2900
Controls						
CSH 9'		3740	4860	4650	1740	3750
CSH 5		670	4450	3160	1680	2490
SPV 351		1720	3610	4560	1420	2830
SE		±624	±259	±270	±275	
Trial mean (genotypes)		2430	3120	3420	1050	
CV(%)		45	14	14	45	

1. RBD, two replications, plot sizes between 8 and 12 m^2.
2. HF = High fertility (N 86: P 56: K 0).
3. LF = Low fertility (N 40: P 20: K 0).

mass (g), the percentage of grains floating in a solution of sodium nitrate (1.3 s.g.), and mass of the product (>1700 um) recovered after pearling a grain sample (20g) for 4 min in a Tangential Abrasive Dehulling Device (TADD) fabricated by an International Development Research Council (IDRC)-funded project at the National Research Council, Prairie Research Laboratory (PRL), Saskatoon, Canada. The percentage of floaters was correlated with TADD pearling recovery (r=-0.64**) confirming our earlier observations using a seed scarifier, that percentage of floaters is negatively correlated with pearling recovery and can be reliably used to select for grain hardness (ICRISAT Annual Report 1983, p. 45). Analysis of variance of the data over the two locations indicated significant genotype x location effects/particularly for percentage of floaters.

Overall heterosis for 100-grain mass was significant and positive while heterosis for grain hardness as expressed by the percentage of floaters and pearling recovery was not significant. These observations confirm our earlier finding that average dominance for grain hardness is partial, and that it is significantly affected by the environment.

Dimpled or Shrivelled Endosperm Mutants

We studied the inheritance of dimpled or shrivelled endosperm mutants of seven sorghum accessions—normal endosperm, SPV 350: basmati, KEP 472 (ICRISAT Annual Report 1979-80, p.7); dimpled, R. vani, M. vani; Sugary, IS 5614; and shrivelled high lysine, LL1 and LL2 (Fig. 5). The last two sorghum lines are photoperiod-insensitive derivatives bred by the All India Coordinated Sorghum Improvement Program (AICSIP) from the shrivelled endosperm, high-lysine (h1) Ethiopian line, IS 11758.

Table 25. Mean grain yield (kg ha^{-1}) of selected advanced varieties evaluated[1] at three locations in India, rainy season 1984.

Entry	Pedigree	ICRISAT Center HP	ICRISAT Center LP	Dharwad	Bhavani-sagar	Mean
A 4053 PC 83R	(SC 108 x Diallel Poll)-2-1-2-3-3	6050	3940	4510	3700	4550
A 926 PC 83R	(FLR 141 x CSV 4)-1-2-4 x Ind-Syn -3-3-4	6760	3360	4750	3200	4520
A 904 PC 83R	ICSV 163 x [CSV 4 x (G.G. x 370)] -2-1-2-6	6930	3290	4620	2960	4450
A 928 PC 83R	(FLR 101 x IS 1082)-4-5-1 x Ind-Syn -235-3-2-2	6170	3810	4650	3120	4440
A 913 PC 83R	ICSV 104 x (E 35-1 x Rs/B 253) -2-1-1-1	6270	3040	4630	3770	4430
A 917 PC 83R	(FLR 274 x CSV 4)-6-2-1	6720	3290	4520	3150	4420
A 908 PC 83R	ICSV 138 x [CSV 4 x (G.G. x 370)] -2-1-1-1-4	7380	2750	4310	2970	4360
Control						
CSH 9		7180	4460	5160	3820	5150
SPH 221		7170	4590	4220	3860	4960
SPV 351		6080	3420	4470	3190	4290
SE		±192	±275	±395	±461	
CV (%)		6	15	16	28	

1. RBD, three replications, plot sizes between 7 and 12 m^2.
2. HF = High fertility (N 80: P 56: K 0).
3. LF = Low fertility (N 40: P 20: K. 0).

Table 26. Mean grain yield (kg ha"[1]) of selected B lines evaluated[1] at three locations in India, rainy season 1984.

Entry	Pedigree	Head exersion (cm)[2]	ICR1SAT Center	Dharwad	Bhavani-sagar	Mean
SPL 90B	FLR 141 x CSV 4-3-3-1-1	12	4840	3490	5350	4560
SPL 79B	Rs/R 21-8614-1-1	10	5050	3680	4870	4530
SPL 160B	Serere 21-8-1-1	15	5620	2790	4870	4430
SPL 120B	Ind-Syn 422-1	2	4900	3970	3920	4260
SPL 151B	Diallel 346-8556-2-1	7	5280	2280	4620	4060
SPL 161B	Serere Elite x IS 9530-2-2	6	5560	2330	3790	3890
SPL 65B	Rs/R 20-682-1-2	9	4970	3120	3490	3860
SPL 95B	FLR 274 x CSV 4-6-1-3-1	5	4620	2400	4500	3840
SPL 100B	FLR 274 x CSV 4-6-1-3-1	7	4770	2470	3850	3690
SPL U7B	Ind-Syn 89-2	18	5200	2040	3560	3600
Controls						
BT x 623		9	5230	3670	4670	4520
296B		2	4860	970	4370	3400
2219B		15	3950	2490	3100	3180
2077 B		8	3760	460	4120	2780
SE		±1.5	±341	±403	±383	
CV (%)		21	10	22	14	

1. RBD, three replications, plot sizes between 3 and 6 m^2.
2. Measured at ICRISAT Center only.

Table 27. Mean grain yield (kg ha^{-1}) of selected sorghum hybrids produced from recently-bred female parents, MA 10 and MA 12 evaluated at three locations in India, rainy season 1984.

Pedigree	ICRISAT Center	Dharwad	Bhavani-sagar	Mean
MA 10 x MR 817	7000	6350	6410	6590
MA 10 x MR 862	7190	6670	5610	6490
MA 10 x MR 846	6720	7280	5250	6420
MA 10 x MR 803	6650	7110	4530	6100
MA 10 x MR 905	6940	7130	4180	6090
Control				
CSH 9	7000	6200	6360	6520
SE	±574	±935	±798	
CV (%)	8	14	16	
MA 12 x MR 855	6970	6110	4730	5940
MA 12 x MR 846	6330	4930	4320	5190
MA 12 x MR 844	6810	5260	4150	5070
Control				
CSH 5	6750	4480	3900	5040
SE	±760	±721	±818	
CV (%)	11	13	21	

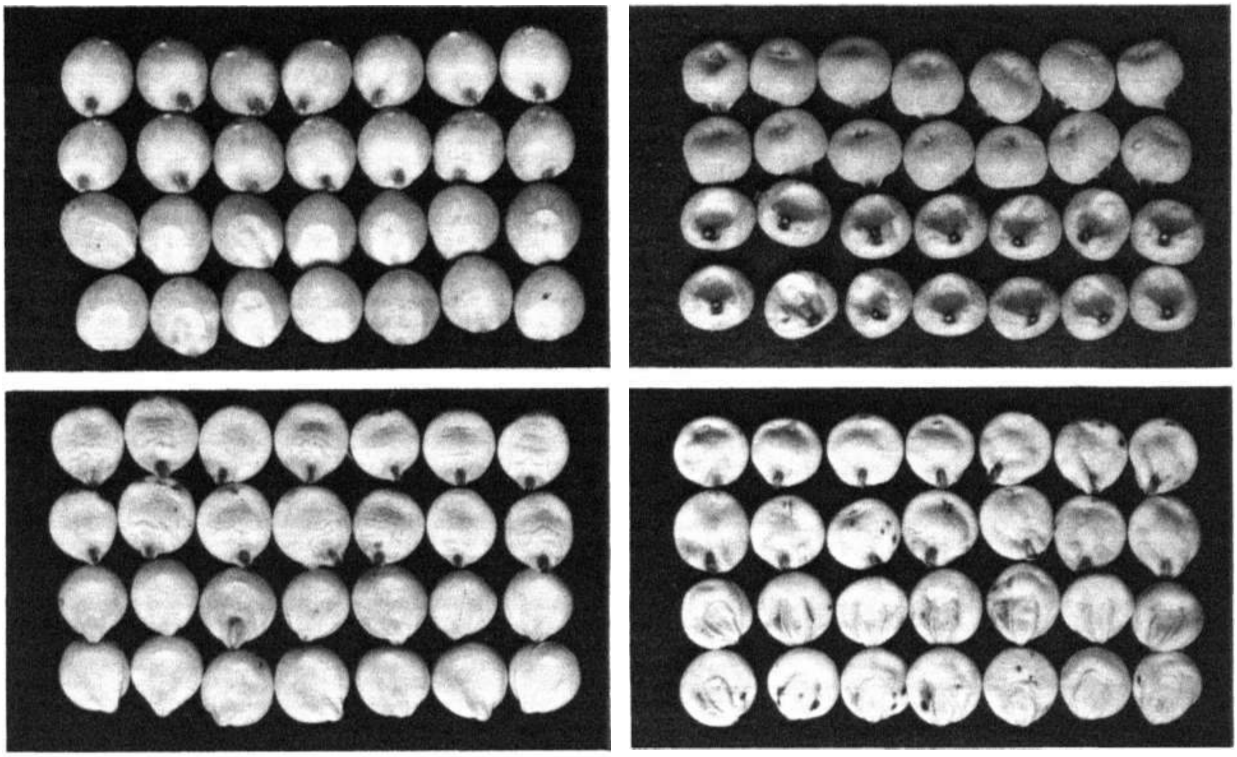
Table 28. Mean grain yield (kg/ha^{-1}) ofselected preliminary sorghum hybrids produced from new ICRISAT male-sterile lines evaluated[1] at three locations in India, rainy season 1984.

Pedigree	ICRISAT Center	Dharwad	Bhavani-sagar	Mean
296A x SPL 69R	7580	8020	5390	6990
ATx624 x SPL 17R	7480	7980	5300	6920
296A x SPL 70R	7660	6960	5730	6780
296A x SPL 68R	7110	8120	4330	6520
SPL204A x SPL 58R	6730	8510	4130	6460
SPL 117A x SPL16R	8260	6690	4180	6380
SPL 180A x SPL 28R	7300	6380	5030	6240
Controls				
SPH 221	7380	6540	5410	6440
CSH9	7470	5590	4450	5840
SE	±204	±484	±465	
CV(%)	5	13	19	

1. RBD, three replications, plot sizes between 3 and 6 m^2.

The sugary line has a hard, crystalline, wrinkled endosperm. Seed of the basmati (scented) and vani types are dimpled on the side opposite to the hilum and have soft endosperms. Crosses between the normal and the four endosperm mutants showed that all the endosperm variants are controlled by single recessive genes. Intercrosses between the mutants revealed that dimpling in basmati and vani types is controlled by the same recessive gene, but the shrivelled endosperms of sugary and high-lysine types are controlled by different recessive genes. Crosses between basmati and vani types resulted in dimpled endosperms, but crosses between basmati x hl, basmati x sugary, sugary * vani, sugary x hl, and vani x hl resulted in normal endosperms. A study of the F_2 and backcross segregation pattern confirmed that endosperm mutants of hl, sugary, and vani are controlled by three different recessive genes and that the gene-controlling dimpling of basmati seed is allelic to that of vani.

Soluble sugar composition in the shrivelled endosperm mutants. We analyzed the total soluble sugars and their composition in the seven sorghum endosperm types included in the inheritance studies. The total sugars were estimated at two stages of grain development: 22 days after flowering (DAF), and at physiological maturity (33 to 39 DAF). Grain sugar content 22 DAF was 2 to 3 times higher than in mature grains. Percentage total sugars in mature grain showed that the LL1 and LL2 types, of high lysine (hl) origin had the maximum quantity (2.85 to 3.41%) followed by sugary types (2.47%). Basmati and vani types have intermediate sugar levels (1.8%), while the normal endosperm type had a relatively lower sugar content (1.5%). Sugar composition determined by thin-layer chromatography at physiological maturity revealed that sucrose and glucose + fructose are the major components of grain sugars. The basmati and vani grain types were characterized by relatively high sucrose and low glucose + fructose fractions. The sugary and high lysine derivatives showed relatively higher glucose + fructose and low sucrose content in their grains.



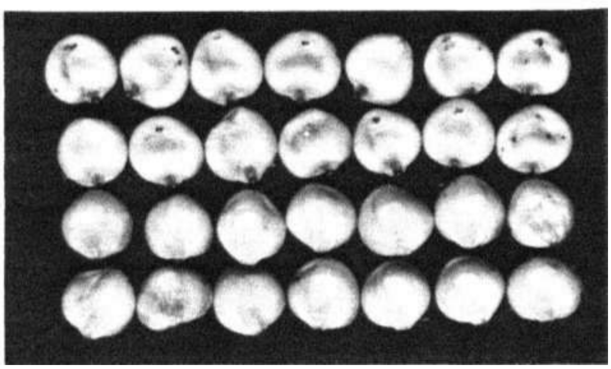


Figure 5. Individual sorghum grains showing a range of endosperm mutations: a. SPV 350, normal endosperm; b. KEP 472, basmati (scented), dimpled opposite hilum, soft endosperm; c. M. vani, dimpled opposite hilum, soft endosperm; d. IS 5614, Sugary, hard, crystalline, wrinkled endosperm; e. LL2, high lysine, shrivelled endosperm.

Food Quality

Dehulling quality. In several countries of Africa and some parts of India, sorghum is dehulled by the traditional method of pounding grains in a mortar with a pestle. The dehulled endosperm is further pounded to grits and/or fine flour depending on the type of food for which it is intended. This tedious and time-consuming procedure is essential before grain can be used for food preparation. We evaluated twelve genotypes of diverse origin, with white grains, and a range of endosperm textures using a TADD. These 12 genotypes were from the International Sorghum Food Quality Trials 1983 (ISFQT83), (ICRISAT Annual Report 1983, pp. 44-45). Grains (20 g) were dehulled for 4 min, and the recovery of dehulled grains (retained on 12-mesh sieve) and brokens (passed through 12-mesh sieve) were determined by mass, and expressed as a percentage. The recovery of dehulled grains ranged from 66.6 to 90.1% (Table 29). Cultivars E35-1, SPV475, and SPH 265 gave more than 88% recoveries, while soft endosperm types like P 721 and ET 187 gave lower recoveries.

Table 29. Detailing quality of 12 sorghum cultivars assessed using a TADD mill, ICRISAT Center.

	Recovery (%)[1]		
Cultivar	Dehulled grain	Brokens	Total
ET 187	62.3«	4.3	66.6
P 721	65.2	1.6	66.8
ET 3491	70.0	4.0	74.0
Tetron	77.0	1.1	78.1
SPH 225	78.5	2.9	81.4
Safra	81.9	1.5	83.4
M 35-1	83.3	1.7	85.0
S 29	81.5	3.5	85.0
IS 12611	85.2	1.2	86.4
SPH 265	87.7	0.4	88.1
SPV 475	86.5	1.7	88.2
E 35-1	89.9	0.2	90.1
SE	±2.7	±0.4	±2.4
Mean	79.1	2.0	81.1

1. All values are means of three determinations.

Digestibility. We analyzed the protein digestibility of sorghum grains by an in vitro method using the enzyme pepsin. The digestibility study involved incubating whole-ground flour and cooked flour (pressure cooked at 5 psi for 20 min), with the enzyme for 3 h at 37° C.

We tested the 12 sorghum cultivars from ISFQT83, for in vitro protein digestibility of their uncooked flour; the scores ranged from 79 to 84% (Table 30). Whole-ground flour was cooked in water (1:10 ratio) which resulted in its gelatinization. The in vitro protein digestibility of cooked flour was lower (range 69 to 77%) than uncooked flour (range 7 to 8%). Further studies are needed to determine the reason for the observed lower digestibility on cooking.

International Testing

Our cooperative activities with national programs involves evaluating international adaptation trials and distributing improved breeding lines. Data from our 1983 International Sorghum Variety Adaptation Trials (ISVAT 83) and International Sorghum Hybrid Adaptation Trials (ISHAT83) were received too late to be analyzed and reported in our 1983 Annual Report. They are reported below.

International Sorghum Variety Adaptation Trial (ISVAT 83)

ISVAT83 consisted of 24 entries including a local control contributed by the cooperator, and 3 control entries (varieties ICSV 1 and ICSV2, and hybrid CSH 5). ISVAT 83 was distributed to over 50 locations in 35 countries, but meaningful data was only received from 16 locations in 12 countries. Mean grain yields of the most promising entries in each country are presented in Table 31. Location mean yields ranged from 884 kg ha"^{1} in Ghana to 5116 kg ha^{-1} at Golden Valley Research Station, Zambia. Variety ICSV 120 IN produced the highest mean grain yields (3838 kg ha^{-1}) across locations. Three other varieties,

Table 30. In vitro protein digestibility (%) of uncooked and cooked sorghum flour for 12 cultivars assessed using pepsin, ICRISAT Center.

		In vitro protein digestibility (%)	
Cultivar	Protein (%)	uncooked	cooked
SPH 475	9.3[1]	82	69
IS 12611	10.8	83	70
Tetron	12.8	79	72
ET 3491	11.5	84	72
S 29	12.4	84	72
ET 187	12.4	79	73
SPH 265	10.5	82	74
SPH 225	10.5	82	74
P 721	13.3	79	75
E 35-1	10.8	82	75
Safra	9.8	84	75
M 35-1	9.7	79	77
SE	±0.1	±2.6	±3.2
Mean	11.2	82	73

1. All values are means of two determinations.

Table 31. Mean grain yields (kg ha^{-1}) of top-yielding entries in International Sorghum Variety Adaptation Trial[1] (ISVAT 83), 1983.

Entry	India (4)[2]	Pakistan (1)	Thailand (1)	Philippines (1)	Ghana (1)	Yemen AR (1)	Zambia (2)	El Salvador (1)	Guatemala (1)	Venezuela (1)	Argentina CD	Honduras (1)	Overall Mean
ICSV 120 IN	2500	1480	4330	2570	1230	3400	6920	5040	3510	5800	4740	4480	3840
ICSV 151 IN	2730	1920	4590	2880	930	3600	5610	4290	3390	6190	4800	3950	3670
ICSV 126 IN	2230	1130	6470	4090	450	3470	6360	5250	4120	3550	1250	5490	3550
ICSV 138 IN	2160	1270	8580	4290	760	3360	5640	3200	2840	5240	4720	2480	3540
ICSV 148 IN	1780	1770	6070	3210	1080	3660	5500	3740	3310	5720	4590	3700	3470
ICSV 155 IN	2460	1610	6620	2250	1030	3660	5360	3870	3570	5400	3670	3750	3420
ICSV 133 IN	2540	1610	4850	1360	1290	2520	6890	3740	3390	5110	540	2580	3180
ICSV 149 IN	2520	1600	3510	1300	1320	3370	5560	4510	3500	5730	890	2790	3110
ICSV 114 IN	3110	950	3740	2540	1200	2000	4420	3630	1670	5460	4190	2470	3070
ICSV 156 IN	2280	1660	3850	2280	850	2600	4750	3910	2400	4710	3860	3960	3040
ICSV 157 IN	2030	1250	4990	1870	810	2130	5330	1940	3770	4620	3300	4420	2990
ICSV 150 IN	1900	1250	3810	880	830	3830	5390	4340	3180	5460	1490	3380	2930
ICSV 137 IN	2330	970	3920	2710	430	2670	4640	1750	2580	1450	4120	2650	2620
ICSV 153 IN	1890	2080	4030	1610	350	3100	3440	1590	2720	2550	3030	1450	2310
ICSV 146 IN	2580	2470	2260	1070	650	1600	2470	2440	3640	3610	650	890	2240
Controls													
ICSV 2	2420	1640	7470	2030	870	2730	6195	4900	3230	5470	3370	3760	3600
ICSV 1	2650	1670	4140	3460	970	2630	4220	5220	3960	5850	4920	3600	3470
CSH 5	2250	1210	4640	430	1750	2330	5560	4490	4820	5590	4560	3560	3220
SE	3	±133	±749	±386	±119	±212	4	±424	±466	±384	±427	±358	
CV(%)		14	29	31	23	13		21	27	15	23	20	

1. RBD, three replications, plot sizes between 8 and 12 m^2.
2. Figures in parentheses indicate number of locations.

	SE range	CV(%) range
3. India	±170-856	5 -31
4. Zambia	±261 -280	25 -45

ICSV 151 IN, ICSV 126 IN, and ICSV 138 IN were among the top yielders at most locations.

International Sorghum Hybrid Adaptation Trial (ISHAT 83)

The ISHAT83 consisted of 24 entries including a local hybrid control contributed by the cooperator and 2 ICRISAT control hybrids, CSH 5 and CSH9. ISHAT83 was distributed to over 25 locations in 20 countries of south Asia and Latin America, but useful data was received from only 12 locations in 7 countries. Mean grain yields of the most promising entries in each country are presented in Table 32. Location mean grain yields ranged from 1081 kg ha^{-1} at Islamabad, Pakistan, to 6793 kg ha^{-1} in Venezuela. Hybrid ICSH 151 IN produced the highest mean grain yields (4193 kg ha"^{1}) across all locations. Hybrid ICSH 110 IN was the top yielder in El Salvador and Honduras, ICSH 145 IN in India, ICSH 133 IN in Pakistan, ICSH 142 IN in Philippines, and ICSH 148 IN in Venezuela.

Contribution to National Programs

In India, ICRISAT-bred variety ICSV I

Table 32. Mean grain yields (kg ha^{-1}) of top-yielding hybrids in International Sorghum Hybrid Adaptation Trial[1] (ISHAT 83), 1983.

Entry	India (5)[2]	Pakistan (2)	Thailand (1)	Philippines (1)	El Salvador (1)	Venezuela (1)	Honduras (1)	Overall Mean
ICSH 151 IN	3650	1910	3070	6360	6100	7610	5120	4190
ICSH 137 IN	3820	2300	2840	5330	6250	5800	4060	4000
ICSH 134 IN	3320	1260	3820	5690	5870	7550	4850	3910
ICSH 133 IN	3380	2480	2840	4620	6040	7010	4370	3900
ICSH 110 IN	3000	1340	4220	3910	7550	7500	5580	3870
ICSH 120 IN	3420	1530	4180	3870	5580	6840	5460	3840
ICSH 138 IN	2720	1480	3330	6000	6630	7580	5460	3750
ICSH 152 IN	3070	1780	2840	6000	5640	7520	4650	3800
ICSH 102 IN	3140	2110	2710	6220	5420	7020	3940	3770
ICSH 145 IN	3940	1040	2980	4490	6380	4670	4520	3730
ICSH 150 IN	2960	1720	1870	5780	6080	7050	5000	3670
ICSH 148 IN	2880	1710	2530	3690	6630	7880	5400	3660
ICSH 142 IN	3160	1060	2600	8000	5610	5250	4730	3640
ICSH 153 IN	3100	1570	2270	5560	6960	6290	4810	3620
Controls								
CSH 9	3460	1420	3330	5200	7100	7020	4330	3930
CSH 5	2790	780	4440	1020	5880	4950	3650	2950
SE	3	4	±744	±875	±600	±374	±404	
CV (%)			42	30	17	10	15	

1. RBD, plot sizes from 3.6 to 6 m^2.
2. Figures in parentheses indicate number of locations.

	SE range	CV(%) range
3. India	±170-856	5 -31
4. Pakistan	±261 -280	25-45

(SPV 351) was formally released by the Central Subcommittee on Crop Standards, Notification, and Release of Varieties for cultivation in all areas where rainy-season sorghum is grown under the name of CSV 11. Two other ICRISAT-bred cultivare, ICSV 2 (SPV 386) and SPH 221, were evaluated in the All India Kharif Minikit Trials, while ICSV 112 IN (SPV 475) was nominated for 1985 Kharif Minikit Trials in farmers' fields throughout India. SAR 1, a *Striga asiatica*-resistant variety was evaluated in minikit trials on Striga-infested farmers' fields in Maharashtra, Andhra Pradesh, and Karnataka states in India.

In Guatemala, ICRISAT-bred sorghum varieties M 90975 and M 91057 were evaluated with good results, and released as ICTA-C 25 and ICTA-C 21

ICRISAT-bred sorghum varieties were tested in various national multilocational trials in many countries in Africa and the Americas. Some of these are S 34 and S 35 in Nigeria and Cameroon, SEPON 80-1 in the Yemen Arab Republic, and M 62641 in Haiti. In India, nine varieties and six hybrids were evaluated in the AICSIP's rainy and postrainy season trials.

We also provided seeds of our improved breeding materials to our cooperators throughout the SAT in the form of nurseries and in response to seed requests. In 1984, we supplied a total of 12800 samples to our cooperators worldwide.

International Cooperation

West Africa

Burkina Faso

Integrated *Striga* Management

Screening. We conducted thirteen trials to screen sorghum cultivars for resistance to *Striga hermonthica* during 1984 at three locations in Burkina Faso: Farako-Ba, Kamboinse, and Yako (Table 33). The trials at Kamboinse and Yako failed because of the severe drought. However, the Kamboinse trials did provide valuable information on seedling establishment (see footnote 3, Table 33). One trial each of the International Sorghum *Striga* Nursery (ISSN) and of late-maturing photosensitive cultivars conducted on farmers' fields in Farako-Ba gave very useful results.

ISSN consisted of seven white-grain derivatives from crosses involving Framida, a highly Striga-resistant, brown-grain sorghum, along with four standard cultivars. Resistance to *Striga* was convincingly demonstrated in this year's checkerboard layout. A few of the derivatives, notably ICSV 1007 HV, 1010 HV, 1006 HV, and 1005 HV exhibited resistance levels comparable to Framida. In addition to resistance to *Striga,* ICSV 1006 HV (Fig. 6) was also comparable to Framida for grain yield, seedling establishment (%), and days to flowering (DF). ICSV 1002 HV, now in pre-extension trials, exhibited a moderate level of resistance.

Extremely high levels of resistance (< 10% of susceptible cultivar CK 60 B) were demonstrated by some locally-grown cultivars such as IS 6961 (Sudan), CVS 122 (Burkina Faso), and Seguetana 5153 (Mali), 'Seguetana' is the local term used by farmers for Striga-resistant cultivars. Seguetana 5153 compared well with Framida for grain yield and seedling establishment. All the

Table 33. *Striga* reaction, grain yield (kg ha^{-1}), and days to flowering (DF) of some white-grain sorghum selections from Framida crosses evaluated in *Striga-sick* plot[1], Farako-Ba, rainy season 1984.

Entry	Pedigree	*Striga*[2]	Grain yield (kg ha^{-1})	DF	Establishment (%)[3]
ICSV 1001 HV	Framida	50 (7.1)	2840	71	86
ICSV 1 HV	E 35-1	329(18.1)	1560	79	45
ICSV 1012 HV	Tetron A	114(10.7)	2240	79	70
ICSV 1007 HV	148 x Framida	63 (7.9)	1810	60	60
ICSV 1010 HV	(146 x CS 3541)-27 x Framida -7-1	33 (5.7)	1380	79	38
ICSV 1006 HV	(146 x CS 3541)-6 x Framida-3-1	66 (8.1)	2560	70	80
ICSV 1005 HV	(Framida x SPV 105)-2-3-1	86 (9.2)	1780	65	64
ICSV 1009 HV	(Framida x SPV 329)-2-1	110(10.5)	1760	66	7
ICSV 1008 HV	(Framida x SPV 105)-2-2-1	154(12.4)	1850	66	73
ICSV 1002 HV	(Framida x E 35-1)-4-2	173(13.1)	1760	78	39
Farako-Ba local	Gnofing	236(15.3)	1080	90	60
Control					
CK 60 B (susceptible)		332[4]	-	-	
SE		±(1.9)	±303	±1.4	
CV (%)			32	4	

1. Checkerboard layout, plot size 6m^2.
2. Mean number of emerged *Striga* plants plot^{-1}. Figures in parentheses are square root transformed values.
3. Number of hills with at least one live plant 2 weeks after sowing as percentage of total hills sown in Kamboinse.
4. Emerged *Striga/* 6 m^{-2} averaged over 108 plots in the checkerboard layout

Figure 6. Sorghum variety ICSV 1006 HV that has resistance to *Striga hermonthica,* compared to susceptible cultivar CK 6013 growing on either side in *Striga-sick* farmer's field, Farako Ba, Burkina Faso, rainy season 1984.

three cultivars are late-maturing and tall, with undesirable grain quality characteristics which are now being improved in our breeding program.

Inheritance of resistance. We investigated the resistance of sorghum cultivars N 13 and IS 9830 to *Striga hermonthica* using generation mean analysis (P_1, P_2, F_1, F_2, BC_1, and BC_2) in pots infested with *Striga* during the summer season. Resistance in both these cultivars was partially dominant over susceptibility of BT x 623 in F_1. The segregation pattern in the F_2 and backcross generations suggested the involvement of a single gene. The segregation ratios, however, were not discrete because of the low heritability of this character. This suggests that it will be difficult to select individual plants in F_2, but selection for such low heritable characters based on F_3 progeny testing in *Striga-sick* plots may be feasible.

Researcher-managed on-farm trials. A few of the cultivars selected for *Striga* resistance and higher yield are tested each year in researcher-managed trials in farmers' fields in four villages, two each in the regions of Boromo (Koho and Sayero) and Yako (Kolbila and Ouonon) in cooperation with our Economics Program. In 1984 we selected one field in each village and tested nine cultivars including one local control in a split-split plot design at two management levels (improved, 100 kg N15:P23:K14 + 50 kg urea ha^{-1} and plowing; traditional, no plowing and no fertilizer) as main plots, two dates of sowing 18 days apart, as sub plots, and cultivars as sub-sub plots. The trial was replicated twice in each village. The objectives of this trial were to select cultivars with: high and stable grain yields i.e., those producing more than local cultivars under both management levels; good seedling emergence especially under traditional management; flowering stability i.e., the type of management should not unreasonably delay flowering in test cultivars compared to local ones. The trial was also designed to select photosensitive cultivars. This we determined by recording the number of days to flowering after the two sowing dates.

During 1984 the trials in all the four villages suffered severe drought. The trial in Ouonon village failed to produce grain. The data on grain yield and seedling emergence from the other three villages are presented in Table 34, together with days to flowering from Koho village. In all three villages analysis of grain yield data revealed highly significant differences between management levels and dates of sowing. Seedling emergence was higher under traditional management in Koho and Sayero because in the plowed plots the soil dried after sowing during the drought. Seedling emergence after the first sowing date was adversely affected at Koho and Kolbila because of poor rains after sowing, but at Sayero, good rains followed the first sowing date and resulted in higher emergence. Cultivar differences in emergence were significant in Sayero and Kolbila. The information on days to flowering from Koho indicate that all the cultivars except ICSV 1014 HV and ICSV 1016 HV are completely, or partially photosensitive. These cultivars flowered earlier after the 2nd sowing date, as did the local cultivar.

The highest overall grain yields were produced by ICSV 1014 HV (703 kg ha^{-1}) and ICSV 1002

Table 34. Grain yield (kg ha^{-1}), seedling emergence (%), and days to flowering (DF) of nine sorghum cultivars, and the effects of management systems[1] and sowing date (DS 1 and DS 2) in three villages of Burkina Faso, rainy season 1984.

	Koho				Sayero		Kolbila		Overall mean	
Treatments	Grain yield (kg ha^{-1})	Seedling emergence (%)	DF DS 1	DF DS 2	Grain yield (kg ha^{-1})	Seedling emergence	Grain yield (kg ha^{-1})	Seedling emergence (%)	Grain yield (kg ha^{-1})	Seedling emergence (%)
Management system										
Improved	1680	71	88	77	290	65	400	70	789	69
Traditional	730	75	98	86	70	80	30	60	279	72
Sowing dates										
DS 1	1290	60	-	-	290	75	280	60	619	65
DS 2	1120	65	-	-	70	70	160	70	449	75
Cultivars										
ICSV 1011 HV	1410	57	94	84	150	48	140	38	590	48
ICSV 1010 HV	950	55	103	88	30	50	180	48	386	51
ICSV 1015 HV	1000	70	98	83	210	67	190	61	466	66
ICSV 1006 HV	1080	86	95	78	260	92	290	87	543	88
ICSV 1002 HV	1570	84	90	78	190	80	210	64	656	76
ICSV 1014 HV	1600	76	80	77	220	79	290	72	703	79
ICSV 1012 HV[2]	-	-	-	-	340	88	280	70	310	79
ICSV 1016 HV	1120	63	91	86	40	54	140	52	435	56
Local	930	86	97	82	160	93	170	88	420	89
SE	±60	±8.6			±41	±9	±21	±6.3		

1. Plot size 8 m^2.
2. Because of planting error this cultivar was eliminated from the analysis of data from Koho village.

HV (656 kg ha^{-1}); these were followed by ICSV 1011 HV (590 kg ha^{-1}) and ICSV 1006 HV (543 kg ha^{-1})- Seedling emergence is a very important factor in West African conditions, and in our trials ICSV 1006 HV, with 88% emergence was almost the same as the local varieties (89%). Other varieties with the beneficial trait were ICSV 1012 HV, 1002 HV, and 1014 HV. ICSV 1006 HV is also more photosensitive than the local variety followed by ICSV 1010 HV, 1015 HV, and 1002 HV. Traditional management only delayed flowering by 4 days in ICSV 1011 HV, and by 6 days in ICSV 1002 HV and the local variety when compared to flowering under improved management conditions.

On-farm testing. Two sorghum varieties ICSV 1001 HV and ICSV 1002 HV (Fig. 7) continued to be tested by various research and pre-extension agencies in Burkina Faso, Cameroon, Mali, Niger, and Togo. Both varieties are being multiplied in Burkina Faso. ICSV 1001 HV was also multiplied in Togo on 11 ha during 1984.

ICSV 1002 HV continued to demonstrate its yield stability despite the drought in Burkina Faso. In a pre-extension trial at the Farako-Ba research station it produced 3600 kg ha^{-1} compared to 1600 kg ha^{-1} for the local cultivar in a trial comparing animal and manual cultivations. Under the latter system it also out yielded the local cultivar by 2500 kg ha^{-1} compared to 1360 kg ha^{-1}. In this trial ICSV 1002 HV flowered 20 days earlier than the local cultivar and resisted grain weathering. ICSV 1002 HV also did well in the eastern Organism Regional de Development (ORD) when tested by national pre-extension agencies in farmers' fields. On average it produced 930 kg ha^{-1} compared to 330 kg ha-$^{-1}$ for

Figure 7. Farmers inspecting sorghum variety ICSV 1002 HV on a Farmers' Day at Kamboinse, in May. This variety in a pre-extension trial at Farako Ba yielded twice as much as the local control, rainy season 1984.

the local cultivar. Farmers like this cultivar because not only does it have stable yields but also grain and fodder qualities suitable for their conditions. The eastern ORD has plans to multiply the seed during the 1985 rainy season.

Temperature Effects on *Striga* Emergence

In our 1982/83 pot experiments we observed that sorghum planted in November was not attacked by *Striga hermonthica* even though it had flowered and matured. When the sorghum was ratooned there was heavy emergence of *Striga* in April/May. We felt that temperature (low in Dec-Jan, and high in March-May) may therefore be an important factor in *Striga* emergence. Subsequently, we designed a pot experiment with monthly plantings round the year to determine: the seasonal *Striga* emergence pattern; effect of temperature and cultivar differences on seasonal emergence pattern, and from this the best date to sow sorghum to coincide with the highest emergence of *Striga,* thus allowing reliable screening.

The results for days to first emergence, days to maximum emergence, days to flowering, and maximum number of emerged *Striga* in relation to sowing date, are shown in Figure 8. Our experiment showed that the first emergence of *Striga* above the soil surface was significantly delayed by sowing in December and January, when air and soil temperatures were at their lowest. It also took the most days for maximum *Striga* emergence in the winter-sown crop. The highest and fastest *Striga* emergence occurred in the summer-sown crop (April and May). The above-ground *Striga* emergence corresponded to a minimum air temperature of approximately 22° C, irrespective of sowing date.

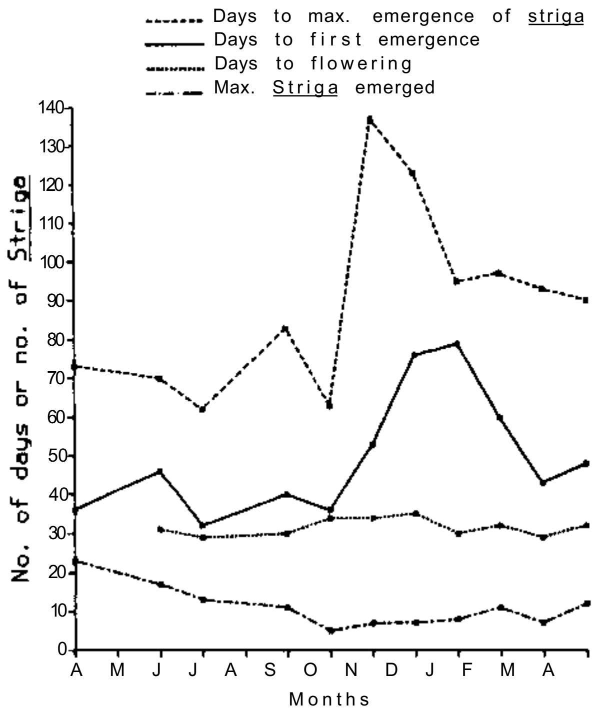


Figure 8. Emergence and flowering behavior of *Striga hermonthica,* Burkina Faso, 1984.

Breeding

The sorghum breeding program located at Kamboins£ Research Station is an integral component of ICRISAT's regional sorghum network in West Africa, and is oriented to develop and identify elite genotypes for the national program, and similar ecological zones of West Africa. Past research results have indicated that many elite introductions have better yield potential but they lack the robust seedling traits, drought tolerance, and grain quality of local varieties. Local varieties, in turn, have relatively poor yields under improved management practices. While it is relatively easy to develop new genotypes, their evaluation under rainfed conditions has been difficult because of the unpredictability of the climate, and the associated effects of pest and disease incidence. The rainfall at Kamboinse was precarious in 1984 and no useful results could be obtained from our experiments. The drought was not so severe at other locations but occurred in varying intensities throughout the region.

Elite progeny evaluation. We evaluated eight long-duration elite F_7 selections from our pedigree breeding program, using a local variety as control in replicated experiments at seven locations. We obtained useful data from four locations. Pertinent results for the four most promising entries are presented in Table 35. At one location (Koho) the trial was also conducted in two replications, with and without soil management and fertilizer inputs. ICSV 22 HV had 12% and ICSV 23 HV 14% yield advantages over the local variety; but ICSV 19 HV and ICSV 24 HV were only marginally better.

We tested a similar number of elite lines derived from F_6 and F_7 generations in replicated experiments at seven locations. Data from four locations of our medium-duration trial and from two locations for the short-duration trial were useful, and the characteristics of the most promising entries are presented in Tables 36 and 37.

For these two maturity durations, ICSV 1002 HV, 16 HV, 14 HV, 15 HV, 7 HV, 8 HV, and 6 HV showed promise. ICSV 1002 HV, originating from the Striga-resistance breeding project, had the highest average yield. All these entries will be further tested during 1985.

Backcross progenies. We visually selected 316 panicles from the F_4 generation of 350 backcross families from F_2 BC_1 F_4 generation. Seed from these panicles was sown in the off-season nursery under irrigation. The harvested F_2 BC_1 F_6 generation progenies will be evaluated in a preliminary yield trial during the 1985 rainy season.

Table 35. Grain yield (kg ha^{-1}) plant height (cm), days to flowering (OF), and seedling vigor (SV) of a few selected long-duration sorghum cultivars, four locations, Burkina Faso, rainy season 1984.

Cultivar	Pedigree	Grain yield (kg ha^{-1})					Plant height (cm)	*DF*	SV
		SA[1]	FB[1]	KH[1]	CB[1]	Mean			
ICSV 22 HV	926*1089	2480	2760	1810	2280	2330	205	75	2.1
ICSV 23 HV	CSV 4 x Sor.B	2000	2180	1380	2320	1970	240	85	1.9
ICSV 19 HV	NES 1077 x 1009	2160	1550	1490	2640	1960	225	85	1.5
ICSV 24 HV	CSV 4 x Sor.B	780	2800	1560	2480	1900	215	85	2.3
Control									
Local variety		1030	2110	1390	1760	1570	395	95	2.4
SE		±723	±493	±282	±294				
CV (%)		44	25	20	13				

1. SA = Saria, FB = Farako-BS, KH = Koho, CB = Contubuel. Plot size 8 m^2.

Table 36. Grain yield (kg ha^{-1}), plant height (cm), days to flowering (DF), and seedling vigor (SV) of some selected medium-duration sorghum cultivars, four locations, Burkina Faso, rainy season 1984.

Cultivar	Pedigree	Grain yield (kg ha^{-1})					Plant height (cm)	DF	SV
		KB[1]	SA[1]	KH[1]	FB[1]	Mean			
ICSV 1002 HV	E 35-1 x IS 8785	700	2690	2690	2560	2140	170	75	2.2
ICSV 16 HV	E 35-1 x 950	940	2780	1810	2690	2050	235	70	1.3
ICSV 15 HV	E 35-1 x 950	780	3100	1600	2150	1910	230	70	1.7
ICSV 14 HV	926 x 1089	510	2710	1770	2130	1780	180	75	2.1
Control									
Local Variety	500	1540	1690	1850	1400	355	80	2.2	
SE		±268	±754	±380	±724		±15	±2	±0.7
CV (%)		40	31	21	32				

1. KB = Kamboinse, SA = Saria, KH = Koho, FB = Farako-BS. Plot size 8m^2.

Table 37. Grain yield (kg ha^{-1}) plant height (cm), days to flowering (DF), and seedling vigor (SV) of some selected short-duration sorghum cultivars, two locations, Burkina Faso, rainy season 1984.

Cultivar	Pedigree	Grain yield (kg ha^{-1}) SA[1]	K.B[1]	Mean	Plant height (cm)	DF	SV
ICSV 7 HV	E 35-1 x Yibdivol	2540	960	1750	170	65	1.0
ICSV 8 HV	E 35-1 x Yibdivol	2700	650	1670	175	70	1.4
ICSV 6 HV	S 13 x VS 702	2420	760	1590	175	70	1.3
Control							
Local variety	2050	660	1360	195	85	2.2	
SE		±414	±199				
CV (%)		18	28				

1. SA = Saria, KB = Kolbila. Plot size 8 m^2.

Screening source material. Screening for sources of resistance to shoot fly *(Atherigona soccata),* stalk borer *(Chilo partellus),* and midge *(Contarinia sorghicola)* continued under natural infestation in cooperation with the national research program entomologist at Farako-Ba.

We confirmed the resistance of some entries identified as resistant (< 2% deadhearts) to shoot fly in 1983, during 1984. They are: IS 5470, IS 5566, PS 18601-3, PS 18822-4, PS 19794, and PS 21318.

The entries that exhibited 10% or less stalk borer attack are IS 2195, IS 2309, IS 5585, IS 8320, IS 13100, IS 18551, and PS 14413. All the promising entries in these three nurseries will be retested in 1985.

Mali

During 1984 we made substantial advances in developing breeding lines and refining selection criteria for sorghums adapted to West African conditions. Our bilateral program continued to work closely with the Agronomic Research Service in Mali.

Seedling Drought Resistance

In March-April 1984 at Cinzana Research Station we compared the seedling performance of various varieties under the prevailing drought conditions using line-source gradient sprinkler irrigation, and in high-temperature drought pits.

We grew 16 varieties of sorghum in replicated rows in both the line-source irrigated field and in small hand-watered pits lined with concrete, filled with soil, and covered with charcoal dust. Day temperatures at 1400 hours at 1-cm depth ranged from 41 to 54°C in the field and from 39 to 61°C in the drought pits.

Field emergence and survival after 37 days in the low-water application treatment (2.16 mm day^{-1}) was correlated with emergence and survival after 11 days in the drought pits (Table 38).

The results of this study give us confidence to adapt the drought-pit method for evaluating seedling temperature and drought resistance. Not only were the drought-pit results well correlated

Table 38. Correlations between sorghum seedling responses in drought pits and in the low-water application treatment of field line-source irrigation, Cinzana, Mali, 1 March -1 April 1984.

Pits	Field Emergence (%)	Survival (%)
Emergence %	0.81**	0.74**
Emergence vigor	0.70**	0.66**
Survival %	0.87**	0.82**
Survival vigor	0.75**	0.71**

with the field results, but the known control varieties performed according to our field observations. CSM 205 and CSM 82 S 50 performed better than CE 90 and E 35-1.

Head Bug Resistance

In previous years we found that open panicled sorghums are less susceptible to head bug *(Eurystylus* sp) attack than compact panicled sorghums (Fig. 9). We also observed that the presence of long, cornaceous glumes seems to significantly reduce head bug attack. In collaboration with the Malian Entomology Program we designed and conducted a factorial experiment to determine the effect of panicle shape and relative glume length on head bug attack. Open, semi-open, and compact panicled selections were chosen in combination with short, medium, and long glumes. The nine treatments were sown at Sotuba. *Eurystylus* sp adults and larvae were counted at the dough stage and grain maturity on five panicles for each treatment in four replications.

Our results indicate the clear influence of glume length on head bug infestation in the panicle (Fig. 10). According to preliminary observations this year, head bug females only laid eggs

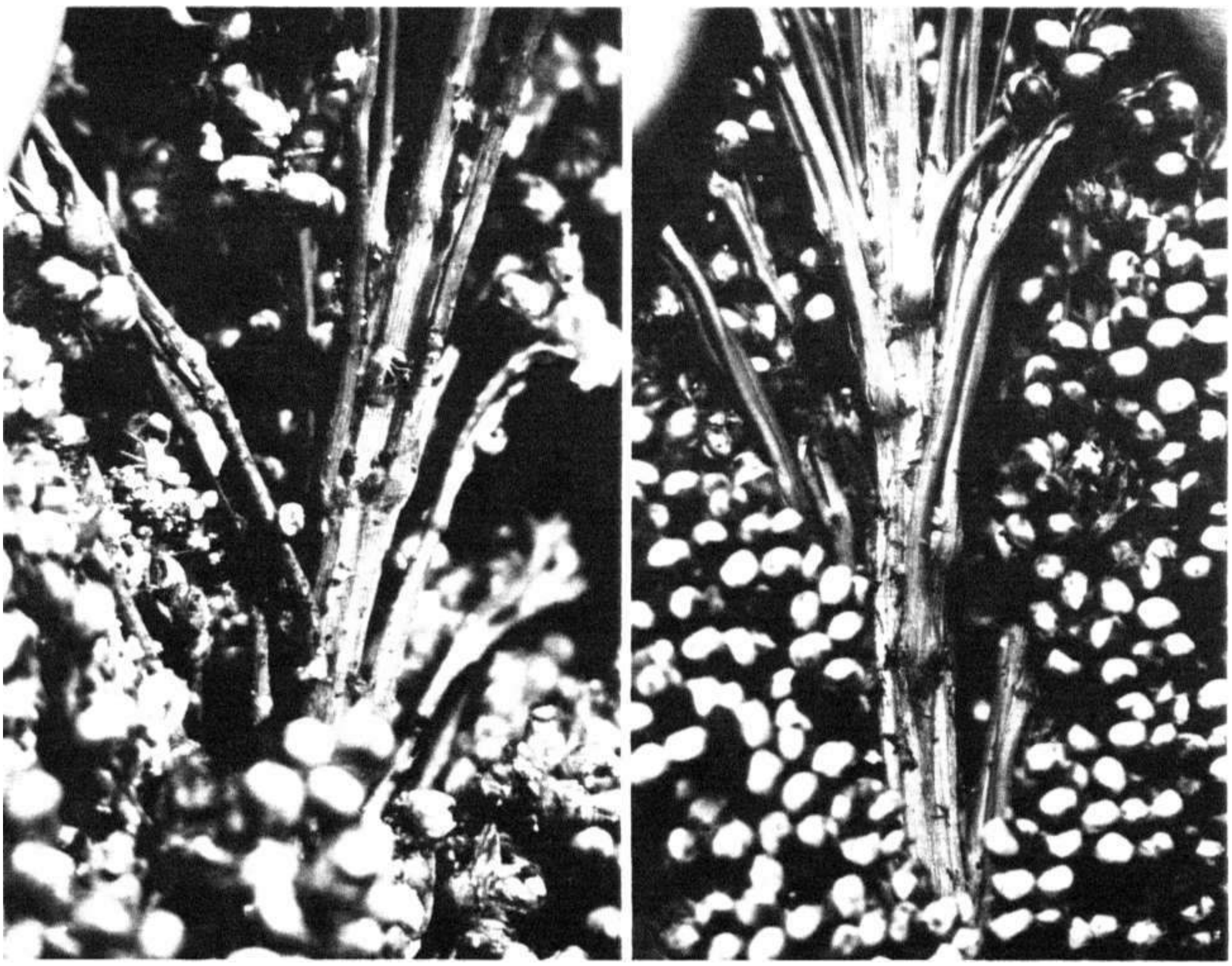


Figure 9. Head bug *(Eurystylus* sp) nymphs developing within the panicle canopy of a susceptible sorghum cultivar (left). Panicle canopy (right) is free from insects although the cultivar developed under the same environmental conditions.

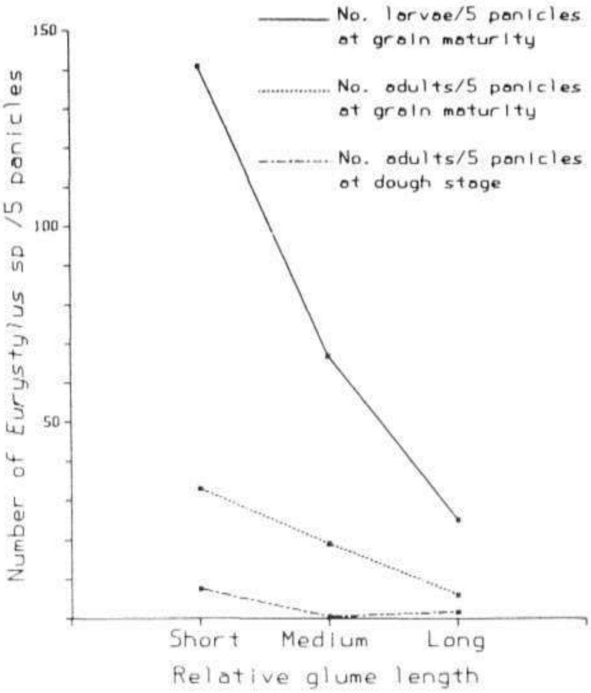


Figure 10. Effect of glume length on numbers of *Eurystylus* species infesting sorghum panicles at dough stage and grain maturity, Mali, 1984.

Three compact panicled sorghums with contrasting short, medium, and long glumes.

into the endosperm at the stylar tips of grains exposed between the glumes. The young growing grains are exposed early (4-5 days after anthesis) in florets with short glumes and are exposed later (6-12 days after anthesis) in florets with long glumes. Thus, long glumes delay the exposure of young grains to egg laying. Since the long-glumed sorghums had relatively few larvae panicle^{-1} at grain maturity, they allowed fewer head bugs to build up populations than those with shorter glumes.

Local Guineense sorghums which have long glumes and open panicles do not suffer from head bug attacks. By incorporating longer glumes into our new sorghum varieties, we hope to reduce head bug infestations.

However, the selection of long glumes presents problems with grain threshing. In long-^{x} short-glume crosses, most of the progeny have adhering glumes that are difficult to thresh. Local Guineense sorghums possess the involute' character which means that at plant maturity the glumes open about 120° so that the grain can be easily threshed. We have recovered large numbers of progeny with that trait, and are now incorporating these into our crosses.

Decortication

We selected the top-performing sorghums from the 1984 Sotuba preliminary yield trials and compared their decortication performance with that of two local varieties, CSM 388 and Sirakorola local, grown under identical conditions.

We decorticated 2-kg grain lots by pounding them using a traditional pestle and mortar. We determined recovery rates and estimated bran adhesion scores by staining with May-Grunwald reagent. The results appear in Table 39.

The recovery rate of 70% (30% bran loss) is typical of local sorghums. The comparable performance of Malisor 84-7 (83 F_6 225) is rare for an improved variety. The association of high recovery with vitreosity suggests that percentage vitreosity could be used as a selection criterion for high recovery.

To Quality

We conducted keeping-quality tests using small grain samples taken from rnultilocational yield trials at harvest. The grain samples were decorticated for 5 min in a TADD and then ground in a coffee mill before being made into small *to* samples.

At Cinzana the drought was severe during grain fill, while Sikasso had humid conditions that favored mold growth during grain fill. The *to* made from grain harvested in these adverse environments was generally less stable than from grain harvested in more favorable conditions. Nevertheless, the *to* from 83 F_6 222 and Malisor 84-7 was stable from all environments. Grain from most of the Sotuba-harvested varieties produce *td* with good stability. We know from past experience that some of these varieties have poor keeping quality unless the bran is removed completely by extending the duration of decortication. We compared the mini-test results from Sotuba grain decorticated for 2.5 and 5 min. The results are shown in Table 40.

Reducing decortication time resulted in a marked separation of varieties for their to-keeping quality. The treatment, and treatment x variety interactions were highly significant.

The results from the 2.5-min decortication on the Sotuba grain samples were similar to those from the 5-min decortication on grain harvested in stressed environments. In 1985, we will try to confirm those results, and will probably adopt the 2.5-minute decortication time for preparing our small routine samples of *td.*

Table 39. Recovery rates (%) vitreosity, and bran adhesion scores of decorticated grain from Sotuba yield trials, Mali, 1984.

Entry	Vitreosity score[1]	Recovery rate[2] (%)	Bran adhesion score[3]
Malisor 84-7	2.13	69.5	3.98
83 F_4 24	3.36	58.8	4.08
82 S 50	3.53	52.5	4.84
A 13120	3.82	61.6	5.25
E 35-1	3.38	65.0	4.96
Controls			
CSM388	2.32	71.8	3.36
Sirakorola local	1.77	69.6	3.06
SE		±1.42	±0.41
CV (%)		3.8	17

1. Vitreosity scored on a 1-5 scale, where 1 = most vitreous, and 5 = most floury. Scores are means of 100 cut grains.
2. Recovery rate: the percentage of dried decorticated product in the total undecorticated grain.
3. Bran adhesion: the mean of 100 stained decorticated grains per replication scored for adhering bran on the dorsal and ventral surfaces. Low scores indicate more complete bran removal.

Table 40. Mini-test results for to-keeping quality of grain samples from 1984 Sotuba yield trial decorticated in the TADD for 2.5 and 5 min.

Entry	2.5-min decortication	5-min decortication
83 F_4 24	1.83	1.16
83 F_4 26	3.33	1.0
83 F_4 88	2.83	1.33
83 F_4 94	2.5	1.0
83 F_4 248	1.83	1.5
83 F_4 292	1.5	1.0
83 F_4 474	4.0	1.16
83 F_6 93	1.0	1.0
83 F_6 222	2.33	1.16
Malisor 84-7	1.0	1.16
SB 722/67	1.33	1.33
S 6	3.67	1.0
S 7	4.0	1.5
A 13120	2.5	1.16
82 S 50	1.66	1.5
E 35-1	4.0	1.33
SE	±0.38	
CV (%)	36	

1. TADD = Tangential Abrasive Dchulling Device.

The excellent *to* stability of grain from the Malisor 84-7 selection was an encouraging result of the 1984 mini-to testing program. Because of its confirmed grain quality and very good agronomic performance (Fig. 11), we used Malisor 84-7 extensively in our subsequent crossing program.

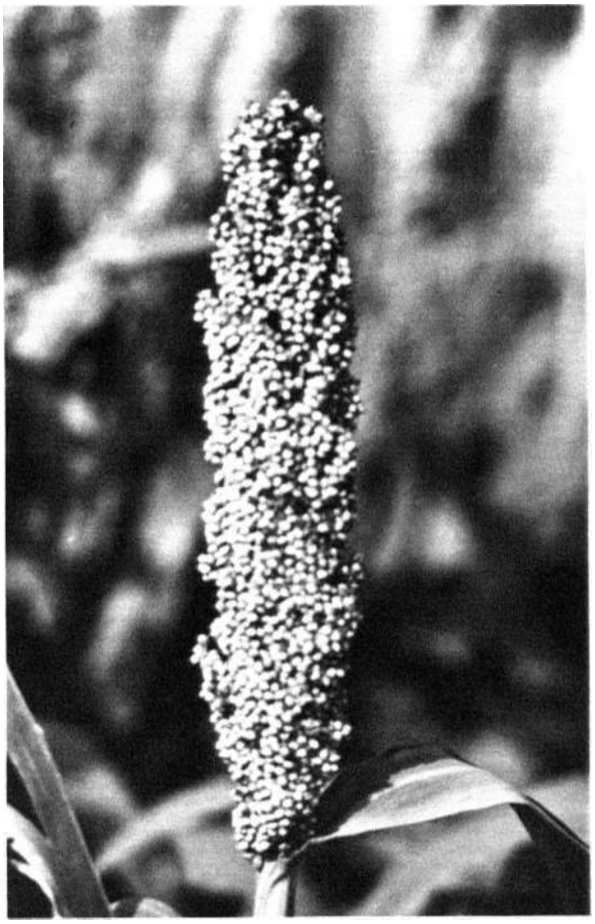


Figure 11. A recent sorghum breeding line Malisor 84-7 (83 F_6 225) that showed grain mold resistance, grain hardness, and good grain yields in 1984 trials. The very short seed branches greatly reduce panicle canopy refuge for head bugs, Mali, 1984.

Population Breeding

We have several populations segregating for genetic male sterility *(ms₃)* that are improved from year to year by full-sib intermating, recombination of F_3 bulk selections, and directed crosses to improve specific traits.

Our basic breeding population was started in 1978 and has been improved by recurrent selection in alternate generations. Since 1981 we have made plant selections within the breeding population. We now have several experimental varieties derived from that population. In 1983, we noticed that there was an unacceptably high frequency of plants with soft seed in the base population, so we decided to make an extensive recombination of vitreous-seeded progeny. We identified two promising F_4 population progenies 83 F_4 474 and 83 GD-Sel 1 with acceptably vitreous seed. Both progenies were segregating for genetic male sterility. We also identified 110 vitreous F_2 to F_6 progenies from our breeding program. All the progeny had seed size greater than 20g /1000 seed. In the 1983 winter season we made a large number of full-sib crosses between the 110 selections and the two F_4 selections. Bulk F_1s were harvested separately for the 83 F_4 474 and 83 GD-Sel 1 parental crosses. The F, generation was grown at Sotuba in 1984 along with the full-sib F, bulk cross from the 1983 base population. We evaluated vitreosity of 1000 panicles from each of the three F, bulk populations by taking the mean vitreosity rating of five grains from each panicle. The distribution of grain vitreosity frequencies for each population is shown in Figure 12.

As illustrated in Figure 12, there was a definite shift in the improved populations toward more vitreous grain. For acceptable decortication, *to* quality, and storage life, we aim to select plants with grain having a vitreosity score less than 2.5, common in local varieties. Our original base population had only 7% individuals with grain vitreosity < 2.5 whereas the 83 F_4 474 population had 31%, and the 83 GD-Sel 1 population had 41%. We expect to obtain large numbers of useful selections from those improved populations. Although it is often difficult to obtain good vitreous progeny from vitreous x non-vitreous crosses, we have rapidly obtained a diverse-based vitreous population by making large numbers of vitreous x vitreous crosses. We hope to similarly expand and diversify our breeding base for the involute glume character.

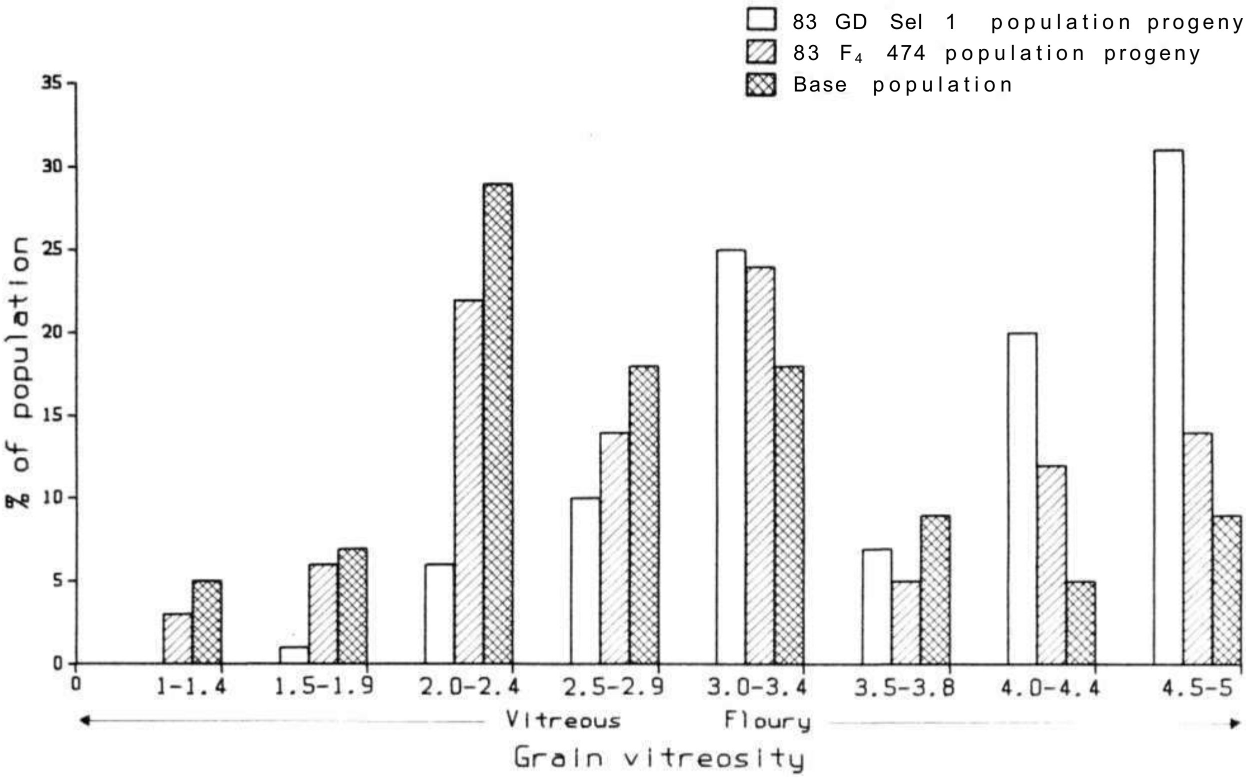


Figure 12. Frequency distributions for grain vitreosity of three sorghum populations, Mali, 1984.

Yield Evaluation of Selected Progeny

We conducted multilocational trials (at short- and medium-season sites), composed of the promising progeny and known control varieties, to investigate the relative grain yield potential of our breeding materials.

At three short-season, very dry locations, we obtained variable yet interesting preliminary performances from three selections—83 F_4 183, 83 F_4 352, and 83 $F_6$173. The selection 83 $F_6$173 also yielded very well compared to CE 90 in an agronomy trial at Bema. 83 $F_4$183 is very early-maturing and has shown promise even on millet soils at Koporo-Keniepe. All three selections will be further tested.

At three medium-season locations, we obtained very good yield levels, up to 3000 kg ha^{-1} (Table 41). Three controls A 13120, E 35-1, and 82 S 50 gave the highest yields but, all three have serious disadvantages under Malian conditions: A13120 is very susceptible to grain mold and charcoal rot; E 35-1 and 82 S 50 have compact heads with short glumes and are very susceptible to head bugs. However all three varieties will continue to be used and tested in Mali.

The experimental variety 83 F_4 26 gave high yields at Kita and Sotuba, and is now being sterilized as a potential female parent for future Malian hybrids.

The vitreous grain variety, Malisor 84-7 also gave good yields at Sotuba and Kita. 83 F_6 26, 83 F_6 93, and Malisor 84-7 will be retained for future testing and selection.

The stable yield levels and grain quality of Malisor 84-7 in the agronomy trials are impressive. In 1985 we will verify its performance for yield and quality compared to 82 S 50, E 35-1, and a local control variety.

Cameroon

Multilocational Testing

In cooperation with the Semi-Arid Food Grain Research and Development (SAFGRAD)/ ICRISAT Program based at Samaru, Nigeria,

Table 41. Grain yields (kg ha^{-1}) of early- and medium-maturing sorghums planted late at three medium-season sites, Mali 1984.

Entry	Mean days to flower	Planting date: 20 Jul Kita	29 Jun Kati-bougou	4 Jul Sotuba	Mean grain yield (kg ha')
83 F_4 24	66	2500	1560	2630	2230
83 F_4 26	70	3280	1520	2950	2580
83 F_4 88	69	2990	2010	1710	2240
83 F_4 94	69	2670	1360	1240	1760
83 F_4 248	72	2550	1680	1850	2030
83 F_4 292	72	1770	1520	1580	1620
83 F_4 474	73	3040	1570	1780	2130
83 F_6 93	68	2920	2200	1870	2330
83 F_6 222	71	2900	1660	2000	2190
Malisor 84 7	74	2810	1410	2580	2270
S 6	84	3490	1800	2270	2520
S 7	82	2590	1710	2010	2100
SB 722/67	79	2220	1610	2330	2050
A 13120	76	2860	2140	3170	2730
Controls					
E 35-1	80	3150	2370	2670	2730
82 S 50	80	2880	1940	3230	2690
SE		±389	±252	±263	
CV (%)		22	32	26	
Rainfall (mm)		800	596	878	

the International Institute of Tropical Agriculture (IITA) sorghum breeder in Cameroon has been testing 1CRISAT material. Sorghum is the main cereal crop in northern Cameroon and in 1983 S 34 and S 35 were grown at 13 locations in different ecological zones together with a local control variety, and E 35-1 and E 38-3 as exotic controls. S 35 did well at 10 locations with low rainfall (300-800 mm a"'), as did S 34 at three locations with higher rainfall (1000-1500 mm a^{-1}. 1983 was a drier-than-normal year but in 1984 there was more severe drought. In a multilocational early-season trial, S 35 ranked first over seven locations, and S 34 ranked first at four locations in a multinational medium-season trial. Both S 35 and S 34 yielded 3000-4000 kg ha^{-1} in agronomic testing.

SAFGRAD conducted on-farm testing and in 1984 correlated data from 88 of their 93 sites. S 35 yielded 85% more than local and exotic control varieties, an average of 1330 kg ha"[1], compared to 720 kg ha^{-1} by the local variety.

S 34 has not been tested by SAFGRAD at high elevations, but in IITA tests at three locations it yielded almost 70% more grain than the local control variety.

Based on 3 years' data from multilocational trials, agronomic data, and 2 years' of on-farm testing, the Government of Cameroon has requested 300 kg seed of each of these high-quality, white-grain varieties that are resistant to most foliage diseases and tolerant to stem borer.

Southern Africa

The initial objective of the regional sorghum and millets improvement program, based in Zimbabwe, is to expand the genetic diversity of these crops in the SADCC region that includes nine countries. In anticipation of the programs' establishment in 1983, we contacted breeders around the world. With their cooperation, we assembled some 5500 entries, primarily of breeding stocks but also including accessions from the world collection, particularly from southern Africa, and Nigeria. We also acquired Zerazera sorghums from Ethiopia and Sudan.

We dispatched seed to Botswana, Zambia, and Zimbabwe. These were subdivided into six sets in Botswana and Zambia, and in October and November 1983, nurseries were sent to Botswana, Malawi, Zambia, and Zimbabwe for evaluation by national research programs.

The nurseries were grown at the Sebele Station near Gaborone, Botswana, Makhanga Station in the Shire Valley, Malawi; Mount Mukulu and Golden Valley stations near Lusaka, Zambia; and Matopos Station near Bulawayo, Zimbabwe. During the year, an A-B nursery of about 150 pairs has ben sown at Matopos to evaluate and increase seed of the female parents of hybrids.

The crops at Sebele and Matopos suffered from severe drought stress while those at Makhanga grew in wet humid conditions, however, the crops at Mount Mukulu and Golden Valley stations grew in almost ideal conditions.

We compiled and evaluated results from these nurseries, and selected entries from them for a crossing block that was sown on the Mzarabani Estate of the Agricultural and Rural Development Authority (ARDA). This is a low-elevation estate in the northern part of Zimbabwe where winter temperatures remain warm enough for good plant growth.

One hundred and seventy-five entries selected for a range in grain color, and maintainer and restorer reaction on cytoplasmic male steriles, were sown on 10 April 1984. Two thousand heads were emasculated, from which we obtained F_1 seed from about 700 crosses. This F, seed harvested on 31 July was sown on 1 August in a 2nd off-season nursery at Mzarabani.

We sowed crossing blocks to test-cross A and R lines but because of a severe water shortage for 20 days at the time of floral initiation the crops failed, so they were ratooned and we will repeat our attempt to make crosses.

Entries in the B-line Observation Nursery came from contributions to the sorghum introduction nursery grown in the 1983/84 season, with additional entries from the sorghum improvement program in Zambia.

Seed of selected entries from the introduction nursery were increased in support of a regional sorghum nursery for the 1984/85 main season. This regional nursery now has 385 entries primarily based on results of the introduction nursery. Twenty entries were provided by the Zambia national program.

SADCC/ICRISAT Sorghum and Millet Improvement Program staff sowing F_1 sorghum seed at the Mzarabani Estate of the Agricultural and Rural Development Authority (ARDA), Zimbabwe. This seed from 700 crosses was harvested the previous day.

The first sorghum crop produced on the SADCC / ICRISAT research station recently established at Matopos, Bulawayo, Zimbabwe.

We also sowed a nursery of 1000 entries received from the ICRISAT Center sorghum pathologist at the Plant Protection Institute, at the Research and Specialist Service's Henderson Research Station, north of Harare, to evaluate resistance to leaf blight *{Exserohilum sorghi).*

Because of the drought in 1983 / 84, most crop improvement activities were conducted at both the Matopos Station and the Bulawayo Sewage Farm, Aisleby, where water for irrigation is assured.

Eastern Africa

Cooperative Regional Trials

The main objective of the Eastern Africa Cooperative Sorghum Regional Trials (EACSRT), is to test the performance of promising varieties in the major sorghum ecological zones of eastern Africa. In the 1983/84 season, four independent trials were organized and distributed to 50 locations in the region. These four trials were for high, intermediate, and low elevations, and very dry lowlands. The trials were grown by the national programs of Ethiopia, Kenya, People's Democratic Republic of Yemen, Somalia, Uganda, Yemen Arab Republic, and Zimbabwe. Results for the 1983/84 crop season from selected stations of these countries are given in Tables 42-44. Since most of the trials for the very dry lowlands failed completely because of drought, no useful data were returned from any station.

High Elevation Trials. For the high-elevation trial, both the Peoples' Democratic Republic of Yemen (PDRY) and the Yemen Arab Republic (YAR) reported the highest grain yields with a mean of about 3000 kg ha^{-1} (Table 42). Yields of almost 4000 kg ha^{-1} for the three entries from YAR were reported from Mukairas, PDRY. At Ibb, YAR, the same three entries, Kadasi, Hamra Hujariya, and Al-Ganad, gave the highest grain yields, about 3500 kg ha^{-1} each. Al-Ganad was the overall highest yielder across all locations. When assessed for agronomic desirability at Katumani, Kenya, Al-Ganad and Hamra Hujariya were the best entries. However, at Lanet, Kenya, these Yemeni entries were scored as agronomically undesirable compared to the local control. An exclusive and prominent feature of the Yemeni entries was their extra-large seed size. The high-altitude Rwanda sorghums with dark brown seed were found undesirable under high altitude situations in YAR and PDRY, and they did not appear well-adapted to the Yemeni sorghum environment.

Intermediate Elevation Trials. At Katumani, Kenya, SVR 8 and ESIP 12 had the best agronomic desirability scores and highest grain yields (Table 43). ESIP 12 has been selected for future trials. Bakomash 80 and SVR 157 were the highest-yielding entries at Ibb, (YAR), although the brown grain of the latter was not acceptable to the Yemeni sorghum consumers. Bakomash 80 has been advanced for further testing in the YAR. The highest-yielding entries at Harare were Bakomash 80 and ESIP 12, with about 10000 kg ha^{-1} compared to 7000 kg ha^{-1} for the local control variety, Chisumbanje.

Low Elevation Trials. The overall mean grain yield for the six stations in five countries that returned data was about 2000 kg ha^{-1} (Table 44). Seven varieties produced approximately 3000 kg

Table 42. Grain yield (kg ha^{-1}) and agronomic desirability (AD) score of the High Elevation Set of the Eastern Africa Co-operative Sorghum Regional Trials (EACSRT), 1983.

Identification	Seed source	Katumani, Kenya	Katumani, Kenya AD[1]	Kakamega, Kenya	Lanet, Kenya AD[1]	Ibb, YAR	Mukairas, PDRY
Kadasi	YAR	840	2.8	-[2]	5.0	3640	3970
Hamra Hujariya	YAR	1670	2.5	-	5.0	3390	3730
Al-Ganad	YAR	2007	2.5	-	5.0	3990	4500
SVR 157	Burundi	1657	3.3	2510	4.0	2840	1930
ETS 2752	Ethiopia	-	4.5	-	5.0	3590	2930
Alemaya 70	Ethiopia	-	4.8	-	5.0	3130	2960
BM 10	Rwanda	1867	3.3	2480	4.0	890	1840
BM 27	Rwanda	2135	3.3	2980	3.7	1730	1810
E 1291	Kenya	1932	3.3	3200	2.7	1960	2040
BJ 2B * BG19	Kenya	939	3.8	-	2.0	770	2340
Local control	Local	-	-	2320	2.0	2990	2020
SE		±369		±236		±386	±99
Mean		1630	3.4	2699	3.9	2630	2734
CV (%)		32.0		20.0		254	6.3
Local control		E 1291		E 525 HR	E 1291 VA 201 26	Safari	Kori

1. Agronomic desirability score: 1 = most desirable, 5 = least desirable.
2. - = Negligible yield.

Table 43. Grain yield (kg ha^{-1}) and agronomic desirability (AD) score of the Intermediate Elevation Set of the EACSRT, 1983.

Identification	Seed source	Katumani Kenya AD[1]	Katumani, Kenya	Ibb, YAR	Harare, Zimbabwe
Buraihi	YAR	3.3	2030	1660	5200
SVR 8	Burundi	2.5	2500	2180	6300
ESIP 12	Ethiopia	1.5	2430	2780	9600
Bakomash 80	Ethiopia	2.3	1540	3460	10500
SVR 157	Rwanda	3.0	2195	3370	7000
Ikinyaruka	Rwanda	3.5	1660	2070	7600
Susa	Rwanda	3.0	2060	2030	2900
2KX 17	Kenya	-	-	570	6900
Local control	Local	-	-	2410	7200
Si-			±477	±280	
Mean		2.7	2060	2280	7000
CV (%)			32.8	21.3	
Local control		-	-	Juraa	Chisumbanje

1. Agronomic desirability score: 1 = most desirable, 5 = least desirable.

Table 44. Grain yield (kg ha^{-1}) of the Low Elevation Set of the EACSRT, 1983.

Identification	Seed source	Katumani, Kenya	Serere, Uganda	Taize, YAR	Zabid, YAR	El-kod, PDRY	Panmure Zimbabwe
Tajarib	YAR	1120	1180	2180	640	2370	2200
SEPON 80-1	YAR	910	950	2680	1390	3500	3800
5DX 160	Burundi	2210	2590	1340	1490	2770	3800
Serena	Uganda	1560	2890	2580	1510	3130	4100
Seredo	Uganda	1630	2630	3300	1490	2900	4700
E525HT	Uganda	1970	1900	2640	1490	3000	3900
2KX 17/13/1	Uganda	3101	610	3080	1060	2070	4500
Tegemeo	Tanzania	530	4601	1810	1240	1430	3800
2KX 17/6	Tanzania	1190	4801	1680	1180	1270	2500
Gambella 1107	Ethiopia	1310	1070	2770	1080	2770	4200
Melkamash 79	Ethiopia	1410	1030	2300	1220	2870	3600
Badege	Rwanda	2590	1900	-[1]	120	2070	-[1]
Urumimbi	Rwanda	2120	2630	-[1]	120	1330	-[1]
76T1-23	Kenya	3801	2100	1430	1410	1330	4300
IS 8595	Kenya	-[1]	1160	840	290	1370	-[1]
Local control	Local		1840	2920	350	1730	3500
SE		±413	±590	±237	±104	±231	
Mean		1430	1590	2260	1010	2240	3800
CV (%)		49.6	59.9	18.2	17.9	17.9	
Local control		76T1-23	E 1937	Gairaia	Beini		Chisum-banje

1. - = Not included in calculation of SE.

SAFGRAD/ICRISAT Regional Sorghum and Millet Project for Eastern and Southern Africa, sorghum introduction nursery,Katumani, Kenya, 1984.

ha^{-1} at El-Kod, PDRY, out of which SEPON 80-1, Gambella 1107, and Melkamash 79 were considered most suitable for the local situation. SEPON 80-1, recently released in YAR, was the highest-yielding entry at Taiz and El-Kod. Although varieties such as Seredo have yielded well in YAR, and PDRY, their grain quality is not considered high enough for the local consumers. Based on their agronomic desirability scores, the best entries for Katumani were Gambella 1107, Melkamash 79, and 5DX 160. At Serere, the best entries were considered to be the Serere-bred lines, Serena and Seredo. At Panmure, Zimbabwe, five varieties, Seredo, Serena, 2KX 17/13/1, Gambela 1107, and 76T1-23 yielded over 4000 kg ha^{-1}.

Introduction nursery. From the 1500-entry introduction nursery evaluated at Katumani during the 1983 short rains, the best 235 entries were advanced for further evaluation in replicated plots.

Based on their agronomic desirability scores, these advanced lines were divided into three test groups and evaluated in the 1984 long rains at Katumani. Based on the results of these trials the selections were further reduced to the best 90, and sown in a replicated trial in the 1984 short rains at Katumani and Kampi ya Mawe. The majority of the promising lines trace their origin to ICRISAT Center, indicating a good correspondence in varietal performance between ICRISAT Center and Katumani. The following most promising lines are being increased for further tests: M 36209, CS 3541-7, ESIP 12, Melkamash 79, [(SC 108-3xSwarna)xE 35-1]-11-6-2, [(148xE 35-1)-4-1x CS 3541 deriv.]-5-3-2, M90812, M66152, [(GPR 148x E 35-1)-4-1 x CS 3541 dial.)-3-4, and [(WAxNigerian bulk)xE35-1)]-5-8-1-3-1-1-1.

Latin America and the Caribbean

Two ICRISAT staff are based at the headquarters of Centro International de Mejoramiento de Maizy Trigo (CIMMYT) in Mexico and are working on sorghum research in Latin America, in close cooperation with the national programs. The main breeding program objectives are to develop cold-tolerant sorghum varieties suitable for high altitudes, with good grain quality for human food, and to improve the local cultivars adapted to low and intermediate elevations in Latin America. The agronomy program is working to develop cropping systems involving ICRISAT-developed material, in both highland and lowland areas.

Breeding

Integrated and intensive breeding efforts are in progress to improve the plant characteristics of sorghum and to meet the production demands from the Latin American countries for sorghum varieties adapted to highland and lowland tropics. The breeding methods employed include conventional as well as population-improvement techniques. We are now developing good male and female parents so that we can produce hybrids for both highlands and lowlands. We annually contribute material to Latin American cooperators by way of the Latin American

Sorghum growing on rocky mountain slopes, Haiti, 1984.

Rainfed Sorghum Yield Trial (LARSYT), that is grown across locations in marginal areas. This year we received 92 requests for the trial. We will also distribute another yield trial that will include hybrids developed by the ICRISAT program.

We continued our cooperation with the Instituto Nacional de Investigaciones Agricolas (INIA). INIA's grain laboratory tested several of ICRISAT's new food-type sorghums to identify the genotypes best suited for food quality. The information gained is used to create an awareness of sorghum grain for direct human consumption in countries such as Mexico, the Dominican Republic, and countries of South America where sorghum is primarily used as animal feed. People in El Salvador, Guatemala, Haiti, Honduras, and Nicaragua are accustomed to using local white-grain sorghum in different forms for human consumption.

The ICRISAT sorghum program at CIMMYT has developed several white-grain varieties suitable for human consumption. Some of these were tested in a trial at 18 sites spread across Mexico's high plateau. Because the lower-than-normal average temperatures during the 1984 growing season did not permit rapid plant development at some sites, and frost did not allow grain formation and/or maturity in some varieties at others, we received grain yield data from only seven locations. VA 110, VA 130 (INIA controls), and IC-CI 4 were the best performers, IC-CI 4 has the additional advantage of white grains suitable for human consumption. The ICRISAT Program at CIMMYT has also developed a white-grain variety BTP 28, that could be used for direct human consumption. BTP 28 is now in the final stages of testing with the national program.

INIA is concerned with the need to strengthen research activities in the highland dry areas of Mexico where there are at least 1 million ha of land potentially suited to sorghum and millet.

In addition to our work with INIA we are also closely involved with the Comision Latinoamericana de Investigadores en Sorgo (CLAIS), a group established in 1982 following a meeting in Guatemala, to coordinate sorghum activities with particular reference to the small farmer in the region. In 1983 CLAIS met in Honduras to review their activities and make plans for the future. CLAIS does not replace the ongoing national program research activities, but complements them by dividing regional research activities in different disciplines among the member countries. ICRISAT staff are involved in advising national research institutions in the region on research planning and execution. These collaborative efforts are coordinated through CLAIS.

ICRISAT's immediate impact in Central America has been in the lowlands and at intermediate elevations. Every year we generate new breeding material at all stages and make them available to cooperators. These breeding materials are in use in the national programs of Colombia, Costa Rica, the Dominican Republic, Ecuador, El Salvaor, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Venezuela, and other South American countries.

To date we have been successful in the following countries with varietal releases derived from ICRISAT breeding material.

El Salvador. 1S1AP Dorado (M 91057 x M 90950) which was identified by the national program using ICRISAT breeding material and has now been released and is in production by a private seed company. This variety is widely adopted from Mexico to South America. San Miguel 1 was released for use by small farmers who use sorghum and maize in associated cropping systems.

Guatemala. Two ICRISAT varieties, ICTA-C25 (M90975) and ICTA-C21 (M91057) will be released in the near future (Fig. 13).

Haiti. M 62641 (SC 108 x CS 354) E 15-5 has shown excellent adaptation in Haiti. The national program in collaboration with the USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL) have increased seed for distribution.

Figure 13. Food-type sorghum variety M91057 (ICTA-C21) that is nearing release in Guatemala.

Honduras. The national program released Tortillero 1 in 1983, but experimental results in 1984 indicated that VG 146 is superior to Tortillero 1 in yield and grain quality and may replace Tortillero 1 in 1985.

Mexico. ISIAP Dorado has been tested in Morelos for the last 3 years and has been shown to outyield the temperate hybrids in the area by 1000 kg ha^{-1}. INIA decided to release this variety and the production department of PRONASE is increasing it on 20 ha. ICRISAT material is also in intensive testing under tropical rainfed conditions in southern Mexico.

Nicaragua. SEPON 77 (PR 113-114) has been released by the INIAP as Nicasor and is in production.

Venezuela. The national program, has already released two ICRISAT varieties (T x 954052 x CS 35411)-15-6 and (SC108-3 x CS 3541)-29-l, which are in commercial production. Results in 1983 indicated that SEPON 77 is outyielding these two varieties, and will be produced on a large scale by the national program this year.

We have a new seed store to hold accessions of genotypes known to be of special value as sources of certain desirable traits, and to maintain sufficient quantities of these to provide seed to regional cooperators on request.

Agronomy

In the highlands of Mexico ICRISAT's research has demonstrated the need to obtain sorghum varieties that mature in less than 140 days, and that can be widely adapted in a variable temperate environment. This variation in environments is exemplified in Figure 14 which shows the growth stages of three highland varieties in relation to rainfall, growing-degree days, and frost-free period at two locations in the valley of Mexico. Tulantongo, 2240 m, has an average 242 frost-free days and 699 mm total annual rainfall. Temascalapa, 2100 m, has 235 frost-free days and 715 mm total annual rainfall. The long period between the last frost and plant emergence (3 months), restricting the effective length of the growing season, is a serious limitation to dryland agriculture in the area. At Tulantongo in 1984 there were 163 frost-free days after the sorghum emerged, but only 142 at Temascalapa. The most important factor in determining yield was a 23-day delay in the killing frost at Tulantongo, thus enabling varieties VA 110 and IC-CI 4 to attain physiological maturity. Grain yields for the two locations are shown in Table 45.

Multilocational testing of lowland varieties in the southern lowlands of Mexico has helped identify superior genotypes with yields above 4000 kg ha^{-1} under dryland conditions. One variety (ISIAP Dorado) will be released shortly. Field testing of varieties in Guatemala and Nicaragua have led to preliminary steps for the release of three varieties by the national programs.

In Honduras we studied the response of three local photosensitive varieties whose crop cycle

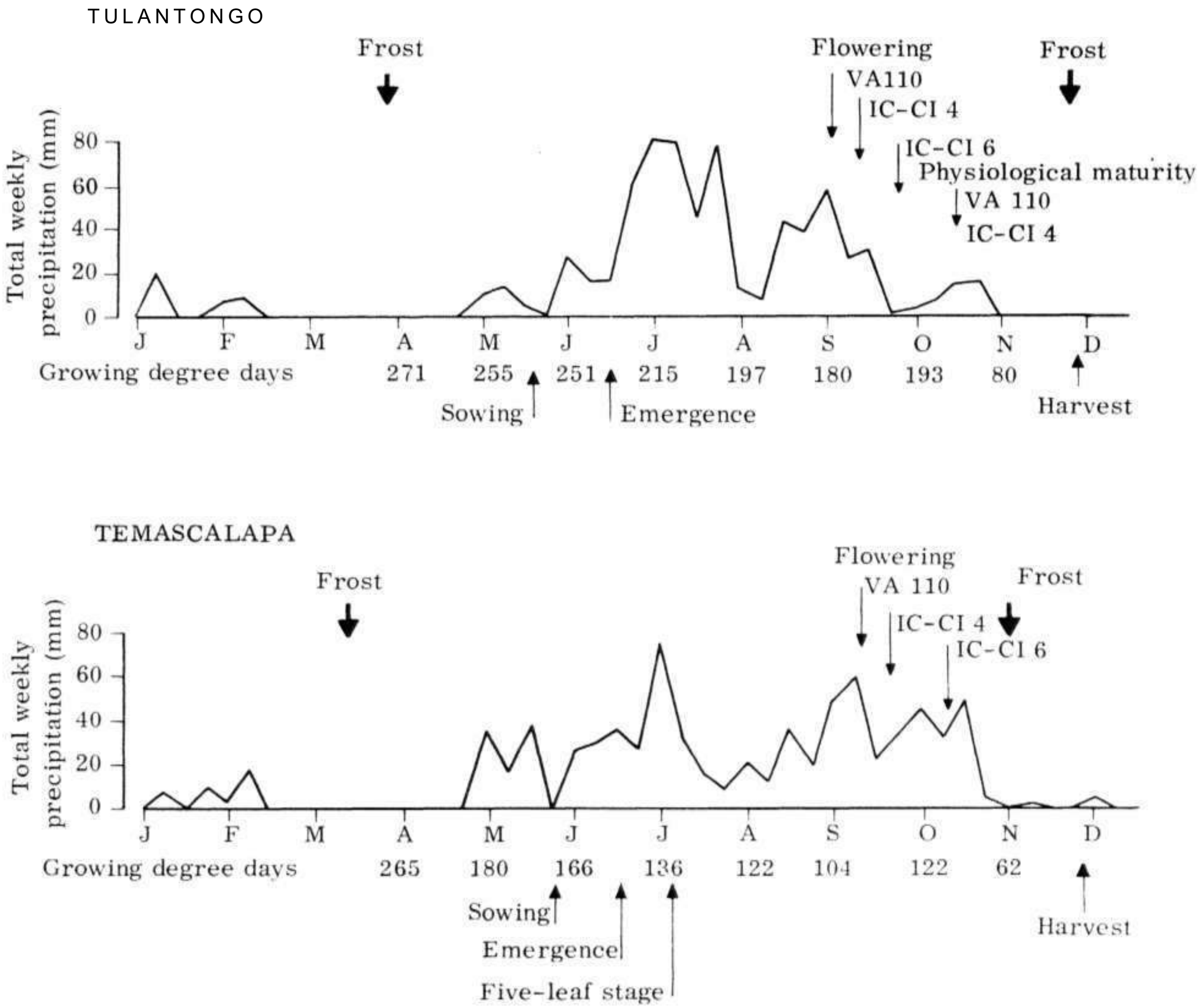


Figure 14. Growth stages of three highland sorghum varieties in relation to rainfall, growing degree days, and frost-free period. Tulantongo and Temascalapa, Mexico, 1984.

Table 45. Grain yields (kg ha^{-1}) of three sorghum varieties at two locations in the valley of Mexico, 1984.

	Grain yield (kg ha^{-1})	
Variety	Tulantongo	Temascalapa
VA 110	4160	450
IC-CI 4	2350	220
IC-CI 6	670[1]	-[2]
SE	±950	±140

1. Values not included in calculation of SE.
2. No grain yield, plants did not mature.

lasts 8 months, under nitrogen fertilizer and plant-density treatments. Our results showed that the 83 x 83 cm spacing used by farmers should not be changed for these tall, leafy genotypes. Nitrogen application at 25 days after emergence (DAE) or at floral initiation had the same effect on plant height and grain yield.

Studies of the effects of planting density and low levels of nitrogen fertilizer on the productivity of two important cropping systems were conducted in Guatemala. Forty kg N ha^{-1} applied at sowing, to improved nonphotosensitive varieties of sorghum in a maize-sorghum relay system

ICRISAT scientist studying maize/sorghum/bean intercropping trial, Guatemala, 1984.

increased the grain yield of sorghum by more than 42% compared to the local farmers' system where fertilizer is not applied to the relay crop. A comparison of the two systems in terms of grain yield and economic returns is presented in Table 46. The mean sorghum yield of 1000 kg ha^{-1} for improved varieties in S_2 compared to S_1 was very low due to drought during the short crop cycle.

We established a common cropping system trial as part of the CLAIS research program. The trial was grown in five countries (El Salvador, Guatemala, Honduras, Mexico, and Nicaragua) to evaluate the most suitable ICRISAT lowland varieties, and to identify the factors limiting to production and use of local photosensitive sorghums. We found two cropping systems, S_1 and S_2 (Table 46), to be the most pertinent for the region. Future research will seek to improve their productivity.

Table 46. Comparison of sorghum grain yields (kg ha^{-1}) and economic returns from two cropping systems. La Pozas, Guatemala, 1984.

Grain yields and economic returns	Cropping systems	
	S_1[1]	S_2[2]
Grain yields (kg ha^{-1})		
Maize	3200 (±250)[3]	1800 (±340)
Beans	-	650 (±130)
Sorghum	2380 (±180)	1000 (±150)
Economic returns		
Direct costs (US $ ha^{-1})	435	499
Gross return (US $)	1036	887
Net return (US $)	601	388
Return on invested capital (%)	138	78

1. S_1 = maize + photosensitive sorghum sown 25 days later.
2. S_2 = maize intercropped with beans (*Phaseolus vulgaris* + improved nonphotosensitive sorghum in relay.
3. SE values in parentheses.

Training

In addition to breeding and agronomic activities ICRISAT staff are involved in training Latin American scientists in sorghum improvement and production. To date we have trained 27 scientists who have now returned to their national programs and are actively involved in sorghum research.

During 1984 eight scientists from Ecuador, Mexico, Nicaragua, and Panama were trained in sorghum improvement and production at our regional base at CIMMYT. We held an intensive one-week course in sorghum breeding and production for 38 participants from different disciplines in their own country at the request of the Dominican Republic. INTSORMIL and the national agricultural research program of the Dominican Republic collaborated in the presentation of this course.

Workshops, Conferences, and Seminars

Workshop on Evaluating Sorghum for Tolerance to Aluminium-Toxic Tropical Soils in Latin America

This meeting was held 27 May to 3 June at the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, jointly sponsored by ICRISAT and INTSORMIL. It was attended by 58 participants from the following countries: Brazil (7), Colombia (28), Honduras (1), India (2), Mexico (2), Peru (3), USA (7), and Venezuela (8) representing national sorghum programs, international centers, international donor agencies for technical assistance, universities, collaborative research support programs, and commercial sorghum companies.

The main objectives of the workshop were to bring together sorghum breeders, plant physiologists, and soil scientists actively conducting Al-toxic tropical research; define areas in Latin America where Al-tolerant sorghum cultivars would have the greatest initial production and utilization impact; discuss the sharing of information and sorghum germplasm from all research programs; and to project the roles of Latin American national programs, INTSORMIL, and ICRISAT in conducting sorghum research in the acid soils environment for the next five years.

The meeting included formal presentations, working groups, and field visits to CIAT experimental sites.

Third Regional Workshop of the Eastern Africa Sorghum and Millet Improvement Network

This workshop was held at Morogoro, Tanzania, 5-8 June, 1984. There were 30 participants, half of them from the host country, and others from Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda, and Yemen (PDR). All participants were active workers in sorghum and millet research. Twenty papers were presented, seven on different aspects of the Tanzanian national sorghum improvement program, the remainder by country representatives who each reported on the sorghum and millet work in his country during the 1983/84 crop season. The results of the 1983 Eastern Africa Cooperative Sorghum Regional Trials (EACSRT) were presented and discussed.

The major recommendations of the workshop were to combine several cooperative sorghum regional trials in eastern Africa and to initiate in 1985 a special regional sorghum screening nursery of breeding lines from ICRISAT Center, Ethiopia, SAFGRAD/ ICRISAT (Kenya), Tanzania, and Uganda. The proceedings of this meeting are available from the SAFGRAD/ ICRISAT Regional Office, Nairobi, Kenya. The Fourth Annual Regional Workshop will be held in Uganda in 1985.

International Sorghum Entomology Workshop

We sponsored jointly with USAID's Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL) and Texas Agricultural Experiment Station, Texas A&M University, a workshop at Texas A&M

University, USA, 15-21 July. The meeting was attended by 35 participants who discussed current knowledge available on sorghum insect pests and determined future research strategies. Of the whole insect complex associated with sorghum, shoot fly, stem borers, midge, and head bugs were identified as the most important. Proceedings including the papers presented and workshop recommendations are in press and will be available from Information Services, ICRISAT.

Sorghum Field Days

A visit was organized at ICRISAT Center 25-27 September to enable scientists from national programs to observe our improved screening techniques and breeding material, and to select varieties of interest to them. Participants came from India, Kenya, Pakistan, and Zimbabwe.

Working Group Meeting on Cereal Nitrogen Fixation

A working group meeting on cereal nitrogen fixation was held from 9-12 October at ICRISAT Center. Twenty-one scientists representing ICAR, Indian Universities, and other Government of India research organizations participated in the meeting, together with seven members of ICRISAT staff. Eighteen papers covering current research findings and plans for future work by different research groups were presented in the main sessions. In addition to these working sessions, there were special sessions on methods of measuring nitrogen fixation associated with cereals, methods of enumerating and quantifying nitrogen-fixing bacteria, and on crop responses to field inoculation with nitrogen-fixing bacteria. In a concluding session, the participants emphasized the need for more standardized, uniform techniques for quantification studies, and more applied field work at different geographic locations. They also identified other priority areas for work on cereal nitrogen fixation. The proceedings are in preparation and will be available from Information Services, ICRISAT.

SADCC/ICRISAT Regional Workshop

A workshop was held in Harare, Zimbabwe, 22-25 October, to make plans for work in 1984/85 and to begin generating information relevant to sorghum and millet in the SADCC region. Sorghum and millet workers representing a range of disciplines from all SADCC countries except Angola and Swaziland attended.

Third Annual Meeting of CLAIS

Coordinated and funded by ICRISAT, this meeting was held in San Salvador, El Salvador, 18-24 November. The CLAIS regional network research activities were reviewed and future strategies and programs finalized. Future CLAIS funding was discussed and a proposal formulated. The 40 participants from 11 countries in the region also had an opportunity to discuss the host nation's national program research. Copies of the meeting's report are available from the International Cooperation Program, ICRISAT.

Regional Workshop on Sorghum Research and Improvement in West Africa

ICRISAT organized a regional workshop in Ouagadougou, Burkina Faso, from 27-30 November. The objective was to provide an opportunity for sorghum researchers to discuss production problems and constraints with the ultimate goal of establishing an effective sorghum research network in the region.

National research programs of Benin, Burkina Faso, Central African Republic, Chad, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Mali, Mauritania, Niger, Nigeria, Senegal, and Togo were represented. Researchers from the CILSS Integrated Pest Control Project, Institute du Sahel, SAFGRAD, ICRISAT Center, and ICRISAT Cooperative Programs in Africa also participated.

The workshop was inaugurated by the Secretary General of the Ministry of Scientific Research and Higher Education of the Government of Burkina Faso. Facets of ICRISAT's

Participants of the Regional Workshop on Sorghum Research and Improvement in West Africa visiting a village near Kamboinse. In the foreground are heads of Framida, a Sirica-resistant sorghum cultivar.

training and research activities were presented together with an 1CRISAT report on the context and role of the Sorghum Research Network in West Africa. These were followed by papers from the national and international organizations attending. On the final day, participants visited a nearby village to see aspects of on-farm activities of the ICR1SAT scientists located at Kamboinse.

The workshop recommendations covered all areas of sorghum research (crop improvement, agronomy, and socioeconomics), man-power needs, documentation, and information dissemination. The effective cooperation of all interested organizations in the region was emphasized. It was also recommended that ICRISAT serve to coordinate the activities of a proposed network system for the region with the help of an advisory committee.

First National Sorghum Workshop of Mexico

Hosted by the University Nuevo Leon at Mavin, Mexico, the meeting was coordinated jointly by ICRISAT staff, the Mexican national program, and the University of Nuevo Leon. Two hundred and ten participants attended from governmental, educational, and private institutions in Mexico and the USA. They reviewed sorghum research in Mexico and defined future research needs and priorities.

Looking Ahead

Physical stresses. We will continue to study the underlying mechanisms associated with resistance to environmental stress. Basic research on biochemical factors affecting crop establishment and mid-season drought resistance will be intensified in collaborative research with the Overseas Development Administration (ODA)-funded scientists from the Welsh Plant Breeding Station, Aberystwyth, and the University of Nottingham, UK.

Biotic stresses. In future, when the necessary HPLC equipment is obtained, we will use the ergosterol assay method to routinely screen breeding material for mold resistance. We will carry out detailed studies on the histopathology of grain infection and colonization by mold fungi, and the role of various factors on resistance. We will also investigate the histopathology of seed infection and transmission of diseases for downy mildew and anthracnose. We will continue with studies on the interaction of root and stalk rot pathogens, drought stress, and sorghum genotypes.

We hope to complete screening the remaining germplasm collection for resistance to shoot fly and produce a final report on identified shoot fly-resistant sources and the resistance mechanisms involved. We will continue to identify and strengthen sources of resistance to stem borer, midge, and head bugs. Research on stem borer and head bug behavior in relation to their host will be continued.

Microbial associations. We will screen more strains of nitrogen-fixing bacteria in the greenhouse to identify more efficient nitrogen-fixing bacteria for inoculation responses under field testing. We will study responses of different cultivars to inoculation with nitrogen-fixing bacteria in fields treated with farmyard manure. We will continue ^{15}N-based experiments to study nitrogen fixation in different lines, and long-term nitrogen-balance experiments in the field.

We will extend the study on genotype dependence of VAM colonization rates and responses by conducting trials outside 1CRISAT Center. We will study VAM's contribution to increasing utilization of rock phosphate by plants in the field. We will continue to standardize the bleeding sap phosphorus technique for screening VAM fungi.

Plant improvement. We will continue to give high priority to the development of multifactor-resistant populations initiated in 1984. These populations are being composited in such a manner that the populations formed have considerable genetic variation for the traits requiring improvement. Once these populations have been developed, they will be random mated 3 to 4 times with mild selection before they are subjected to recurrent selection.

We will evaluate the combining ability of our new male-sterile lines and distribute the most promising ones to national programs for use in the production of adapted hybrids. We will continue to search the germplasm collection for entries that are able to restore fertility of nonmilo-cytoplasm male steriles. At the moment, the commercial use of available nonmilo male steriles is limited because they do not yet have restorers.

International testing. In future, we will conduct international adaptation trials on a biannual basis. We believe that this is convenient and useful as it will give us ample time to receive and analyze data of previous international trials before dispatching new sets of international trials. Our next international adaptation trials will be distributed early in 1985 to reach our cooperators in time for sowing at the beginning of their rainy seasons.

International Cooperation

Burkina Faso. On-farm trials will continue, both in the ISSN and those managed by our researchers. Intensive screening of new cultivars, particularly those with the low *Striga* stimulation trait, will be undertaken to identify new sources of resistance. We will undertake further improvement of such promising breeding lines as ICSV 1002 HV, and 1CSV 1006 HV. Strengthening of resistance through gene pyramiding will be intensified.

We will screen various crops to identify potential *Striga* trap crops and will begin a study of the interaction between temperature, sorghum growth stages, and *Striga* seed germination and emergence.

More emphasis will be placed on the evaluation of local genetic resources, and on the identification of superior landraces possessing specific resistance traits against prevailing biotic and abiotic factors that reduce and destabilize yield. Such landraces can be appropriately used in the breeding program to generate useful lines adapted to the different ecological zones in the region.

We will concentrate on the pre-release testing of promising material, and develop with national programs and other cooperators, networks of multilocational testing and on-farm research capabilities.

Mali. During the last 5 years we have gathered sufficient agronomic information on improving cereal/cereal and cereal/legume intercropping systems with available cereal and legume cultivars. Presently these findings on agronomic factors such as fertility requirement, crop density, time of planting and harvesting, etc., are being combined to develop packages of practices for further evaluation. Large scale testing of these options in comparision with the existing practices are planned for the 1985 growing season.

Future research will focus on new systems that were not studied earlier. Sorghum or millet with groundnut are important intercropping systems particularly in groundnut zones. Pigeonpea is a recently-introduced promising legume crop.

Other agronomic research during 1985 will include collaborative research with Malian national agronomic programs on soil and water management and evaluation of alternative traction equipment. Studies on weed control, particularly on *Striga,* will also receive consideration.

Our breeding programs in Mali and other locations in West Africa are at a stage of releasing new cultivars. Some were evaluated for their agronomic performance in 1984. More sorghum cultivars from Mali and other breeding programs will be further evaluated both under sole and intercropping. Studies to examine their response to varying levels of agronomic inputs will be stregnthened.

SADCC / ICRISAT Program. We will continue introduction and preliminary evaluation at five research stations, one each in Botswana, Malawi, Tanzania, Zambia, and Zimbabwe.

The varietal improvement program will be initially strengthened by pedigree breeding. In future years we will consider recurrent selection procedures. We will develop both white- and red-grain varieties suitable for making thick porridge and opaque beer.

We will further confirm the most important yield-limiting traits, and identify the best locations in the region for screening. We will continue to diversify and select seed parents for hybrids, identify good seed and pollinator parents, and encourage the commercial use of F_1 hybrids by farmers in the region.

We will increase our contribution in support of the research facilities in national programs related to sorghum and millets as our base at Matopos takes shape. The first major effort will be the development, jointly with the Department of Research and Special Services, of a 6-8 ha research station with an assured source of water at Mzarabani Estate in Zimbabwe for trials in future off-seasons, since crop growth was normal for both off-season crops at that estate in 1984.

Publications

Institute Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Sorghum root and stalk rots: a critical review: proceedings of the Consultative Group Discussion on Research Needs and Strategies for Control of Sorghum Root and Stalk Rot Diseases, 27 Nov-2 Dec 1983, Bellagio, Italy. Patancheru, A.P. 502 324, India: ICRISAT. 267 pp.

Ramaiah, K.V., Parker, C, Vasudeva Rao, M.J., and Musselman, L.J. 1983. *Striga* identification and control handbook. Information Bulletin no. 15. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 56 pp.

Ramaiah, K.V., Parker, C, Vasudeva Rao, M.J.,and Musselman, L.J. 1983. [*Striga* identification and control handbook.] (In Fr.) Manuel di' Identification et de Lutte Contre le *Striga.* Information Bulletin no. 15. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 56 pp.

Tandon, H.L.S., and Kanwar, J.S. 1984. A review of fertilizer use research on sorghum in India. Research Bulletin no. 8. Patancheru, A. P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 59 pp.

Journal Articles

House, L.R. 1984. Sorghum breeding: an international programme outlined. SPAN (UK) 27(3): 132-134.

Huda, A.K.S., Madhusudan Reddy, D., and Seetharama, N. 1983. Effect of moisture stress on yield components of *Sorghum bicolor* (L.) Moench. Sorghum Newsletter 26:129-130.

Kanwar, J.S., Rego, T.J., and Seetharama, N. 1984. Fertiliser and water-use efficiency in pearl millet and sorghum in Vertisols and Alfisols of semi-arid India. Fertiliser News 29(4):42-52.

Maiti, R.K., Prasada Rao, K.E., Raju, P.S., and House, L.R. 1984. The glossy traits in sorghum: its characteristics and significance in crop improvement. Field Crops Research 9:279-290.

Maiti, R.K., Ramaiah, K.V., Bisen, S.S.,and Chidley, V.L. 1984. A comparative study of the haustorial development of *Striga asiatica* (L.) Kuntze on sorghum cultivars. Annals of Botany 54:447-457.

Murty, D.S., and House, L.R. 1984. Components of generation means for resistance to grain mold causing fungi, *Curvularia* and *Fusarium* in sorghum. Cereal Research Communications 12(3-4):237-244.

Murty, D.S., Patil, H.D., and House, L.R. 1984. Studies on flour particle size and endosperm texture in sorghum. Journal of Food Science and Technology (India) 21(6):359-363.

Murty, D.S., Subramanian, V., Suryaprakash, S., Patil, H.D., and House, L.R. 1984. Amylase activity and sprout damage in sorghum. Cereal Chemistry 61(5):415-418.

Reddy, S.J., Maiti, R.K., and Seetharama, N. 1984. An iterative regression approach for prediction of sorghum *(Sorghum bicolor)* phenology in the semi-arid tropics. Agricultural and Forest Meteorology 32(3-4):323-338.

Sharma, H.C., and Agarwal, R.A. 1984. Factors imparting resistance to stem damage by *Earlas vittalis* F. (Lepidoptera:Noctuidae) in some cotton phenotypes. Protection Ecology 6:35-42.

Soman, P., Peacock, J.M., and Bidinger, F.R. 1984. A field technique to screen seedling emergence of pearl millet and sorghum through soil crusts. Experimental Agriculture 20:327-334.

Verma, P.K., Wade, L.J., Peacock, J.M., Seetharama, N., Sai Prasad, J., and Huda, A.K.S. 1983. Leaf area response to water and nitrogen stress in sorghum. Sorghum Newsletter 26:130-132.

Conference Papers

Andrews, D.J., Mughogho, L.K., and Ball, S.L. 1984. Sorghum and millet production in Africa: problems and prospects with new varieties. Pages 85-90 *in* Proceedings of the CAB's First Scientific Conference, 12-18 Feb 1984, Arusha, Tanzania. Farnham Royal, Slough, U.K.: Commonwealth Agricultural Bureaux.

Gebrekidan, B. (ed.) 1984. Sorghum and millet improvement in eastern Africa: proceedings of the Third Regional Workshop on Sorghum and Millet Improvement in Eastern Africa, 5-8 June 1984, Morogoro, Tanzania. Nairobi, Kenya: SAFGRAD/ICRISAT Program. 255 pp.

Gebrekidan, B. 1984. Results of the Eastern Africa Cooperative Sorghum Regional Trials 1983/84. Pages 196-225 *in* Sorghum and millet improvement in eastern Africa: proceedings of the Third Regional Workshop in Sorghum and Millet Improvement in Eastern Africa, 5-8 June 1984, Morogoro, Tanzania. Nairobi, Kenya: SAFGRAD/ICRISAT Program.

Giller, K.E., Wani, S.P., and Day, J.M. 1984. Comparisons of the amount of nitrogen fixation associated with millet and sorghum cultivars by isotope dilution. Page 41 *in* Abstracts of the Third International Symposium on Nitrogen Fixation with Non-Legumes, 2-8 Sep 1984, Helsinki, Finland. Helsinki, Finland: The Finnish National Fund for Research and Development (SITRA).

Huda, A.K.S., Sivakumar, M.V.K., Virmani, S.M., Seetharama, N., Sardar Singh, and Sekaran, J.G. 1984. Modeling the effect of environmental factors on sorghum growth and development. Pages 277-287 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Jordan, W.R., Clark, R.B., and Seetharama, N. 1984. The role of edaphic factors in disease development. Pages 81-97 *in* Sorghum root and stalk rots: a critical review: proceedings of the Consultative Group Discussion on Research Needs and Strategies for Control of Sorghum Root and Stalk Rot Diseases, 27 Nov-2 Dec 1983, Bellagio, Italy. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Mughogho, L.K., and Pande, S. 1984. Charcoal rot of sorghum. Pages 11-24 *in* Sorghum root and stalk rots, a critical review: proceedings of the Consultative Group Discussion on Research Needs and Strategies for Control of Sorghum Root and Stalk Rot Diseases, 27 Nov-2 Dec 1983, Bellagio, Italy. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Peacock, J.M., and Heinrich, G.M. 1984. Light and temperature responses in sorghum. Pages 143-158 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Ramaiah, K.V. 1984. Physiological specialization of *Striga hermonthica* and crop specificity. Pages 58-65 *in* Third International Symposium on Parasitic Weeds, 7-9 May 1984, ICARDA, Aleppo, Syria. Aleppo, Syria: International Center for Agricultural Research in the Dry Areas.

Ramaiah, K.V. 1984. Patterns of *Striga* resistance in sorghum and millets with special emphasis on Africa. Pages 71-92 *in Striga:* biology and control: papers presented at a Workshop on the Biology and Control of *Striga,* 14-17 Nov 1983, Dakar, Senegal. Paris, France: ICSU Press, and Ottawa, Canada: International Development Research Centre.

Seetharama, N., Mahalakshmi, V., Bidinger, F.R., and Sardar Singh. 1984. Response of sorghum and pearl millet to drought stress in semi-arid India. Pages 159-173 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Wani, S.P., and Dart, P.J. 1984. Nitrogen fixation associated with sorghum and pearl millets. Page 92 *in* Abstracts of the Fourteenth Steenbock Symposium on Nitrogen Fixation and CO_2 Metabolism, 17-22 June 1984, Madison, USA. (Abstract only.).

Miscellaneous

Guiragossian, V., and Herrera, L.R. 1984. Mejoramiento genetico del sorgo (metodos y procediemientos). [In Es.] Marin, Nuevo Leon, Mexico: Universidad de Nuevo Leon, Facultdad de Agronomia.

Peacock, J.M., and Wilson, G.L. 1984. Sorghum. Pages 249-279 *in* The physiology of tropical field crops (Goldsworthy, P.R., and Fisher, N.M., eds.). Chichester, UK: John Wiley.

Theses

Hagi, H.M. 1984. Gene effects for resistance to stem borer *(Chilo partellus* Swinhoe) in sorghum *(Sorghum bicolor* [L.] Moench). M.Sc. thesis, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad, Andhra Pradesh, India.

PEARL MILLET

Contents

Cover photo: A Malian millet breeder evaluating pearl millet F_4 progeny at Kaporo Keniepe, Mali, 1984.

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PEARL MILLET

Nineteen hundred and eighty four has been, in several ways, an encouraging year in ICRISAT's efforts to improve and extend research on pearl millet, particularly on the African continent. The drought conditions in the Sahel provided an opportunity to evaluate our materials in as dry a year as we can expect in this area. Varieties developed by ICRISAT scientists in cooperation with national programs maintained the same advantage over farmers' local varieties under drought conditions (and at reduced yield levels) that they had in previous years under better rainfall. These varieties have now been released in three countries (Senegal, Niger, and Sudan). At the ICRISAT Sahelian Center (ISC) where the annual rainfall of 265 mm was the lowest on record this century, nearly 80% of the breeding materials produced at least some grain, suggesting that ICRISAT has the genetic base to produce varieties which will provide better yield stability in the fluctuating rainfall of the Sahel. Pearl millet research at the ISC has progressed to a level where breeding products will be evaluated at locations in Mali and Niger beginning in 1985.

ICRISAT also began work on millet improvement in southern Africa, as part of the Southern African Development Coordination Conference (SADCC)/ICRISAT Sorghum and Millet Improvement Program centered in Bulawayo, Zimbabwe. Observations on the first plantings gave us hope that materials from ICRISAT Center will be more directly useful in this region than they are in Sahelian Africa, and that the SADCC project can draw heavily on breeding work in India.

ICRISAT open-pollinated varieties, both synthetics and population varieties, continued to do very well in All-India Coordinated Trials and in minikit trials on farmers' fields. Acreage of WC-C75 expanded rapidly to nine states this year with an estimated coverage of at least 300 000 ha, and prospects for a wide acceptance of this variety seem bright. In our research fields, more effort is being put into building a better base for future breeding of F_1 hybrids. We are making many more crosses specifically for the production of new male-sterile lines, making more systematic efforts to select elite pollinators for these male-sterile lines, and investing more effort into breeding resistance to smut and ergot, as well as downy mildew into hybrid parents.

We also feel that we are making steady progress in understanding the basis of genotype adaptation to some of the limitations to crop yield arising from the difficult climatic and edaphic environments in which the crop is grown. While we are not yet ready to begin large-scale breeding for adaptation to these limitations, we are beginning pilot-scale selection experiments which will tell us whether breeding for adaptation to low soil fertility, drought, and other constraints is possible.

These and other projects are described in the following pages. Research in the two main core programs, ICRISAT Center and the ISC, are described together in the first section of the report, and research efforts at the national and regional level are described under International Cooperation.

Physical Stresses

Crop Establishment

Failure of a crop to establish is a common problem in millet growing areas. The reasons for failure may be many: poor germination, poor emergence due to presence of a soil crust, or due to inadequate seedbed moisture, seedling loss due to drought, high temperature, insect damage, and diseases. Research on this problem at ICRISAT Center focuses on improvement in emergence, and work at the ISC concentrates on improving survival of seedlings after emergence.

High Soil Temperature and Seedling Emergence

Our studies on farmers' fields in Rajasthan indicated that high soil temperatures (>40°C) are one of the causal factors of poor seedling emergence and poor crop stands. We developed a technique to study the effect of high soil temperature on seedling emergence (ICRISAT Annual Report 1982, pp. 41-42) in which naturally-occurring diurnal changes in soil temperature can be reproduced, while maintaining optimum seedbed moisture for germination and emergence. This technique allows screening for the ability of seedlings to germinate and emerge under high soil temperatures (40-50° C), without the common confounding effect of inadequate seedbed moisture.

With this technique it should be possible to select for improved emergence ability if there is genetic variation for this trait in the germplasm. To assess the potential variability available, we screened 117 genetic resource accessions from Rajasthan, India, six Sahelian countries, and two southern African countries, using daily maximum soil temperatures of 45 and 50°C (at 2 cm depth).

Increasing maximum temperature (from 45-50° C) reduced mean percentage emergence from 71 to 36% and the range of genotype values from 20 to 100% to 0 to 30% (Fig. 1). At 50° C only 8% of the entries achieved a satisfactory (60-80%) emergence compared to 47% at 45° C. There were, however, clear differences among genotypes in ability to tolerate a soil temperature of 50°C, which indicates that selection/breeding for this capability may be possible.

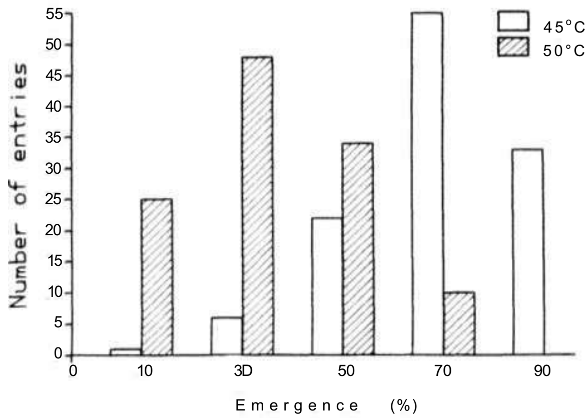


Figure 1. Frequency diagram of percentage emergence of pearl millet seedlings at 45 and 50° C daily maximum soil surface temperature. Percentages are means of classes of twenty percentage points. ICRISAT Center, 1984.

Seedling Establishment under Drought Stress

We used a modified line-source sprinkler irrigation system to screen for drought resistance during seedling establishment (from emergence to about 20 days after sowing (DAS). The irrigation gradient was imposed 7 to 10 DAS and plants were harvested 30 DAS. Percentage plants surviving and growth of the plants was linear with increasing moisture as reported earlier for grain yields (ICRISAT Annual Report 1983, pp. 71-73). This implies that a screening method using two water levels, high and low, is likely to be as effective as the line-source system. We are developing and testing a screening method using two moisture treatments.

Our results also indicate that there is an optimal stress level for screening. Excessively severe stress leads to high variability in the plant character under observation and to loss of discriminative power (Fig. 2). We are now evaluating soil-water balance models to determine the amount of irrigation water necessary to obtain optimum genotype differentiation for any expected evaporative demand.

Seedling Establishment under High Soil Temperature

The technique developed to screen for emergence in high soil surface temperatures (described above) was tested as a screen for millet seedling tolerance of high temperature conditions. Pots of 10 seedlings each were subjected to 24-h, 48-h, or continuous heating under infrared bulbs set 52 cm above the soil surface, beginning at 7 DAS. The soil surface was covered with a 0.5 cm layer of charcoal to increase surface heating and the pots were placed in a water bath to

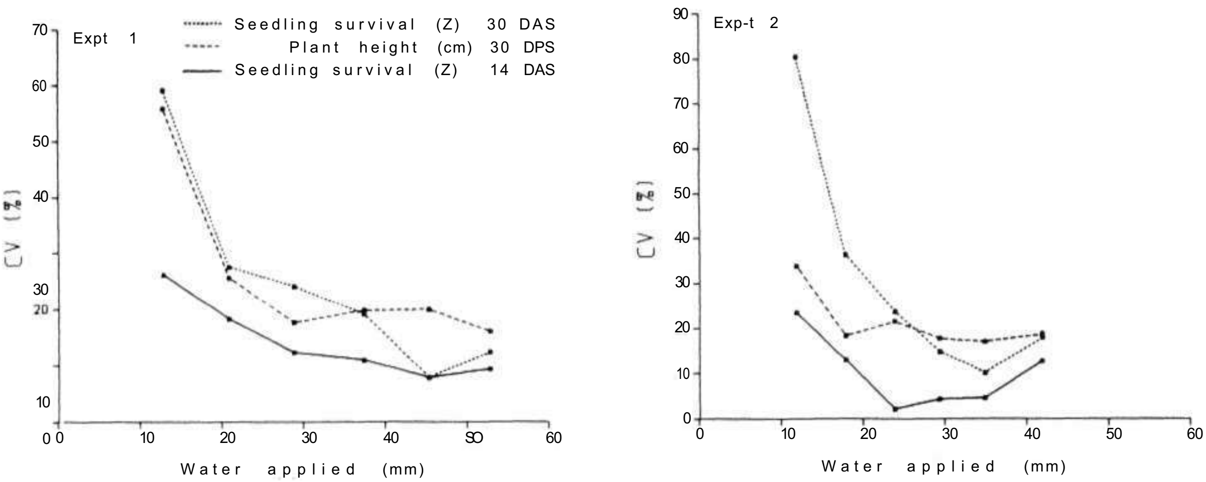


Figure 2. Coefficient of variation for seedling survival (%) in pearl millet at 14 and 30 DAS, and for plant height (cm) at 30 DAS in relation to the amounts of water applied at 7-10 DAS. Data from two separate experiments, ISC, 1984.

maintain adequate soil moisture. Temperatures rose to 48°C at 2 cm soil depth within 8 h from the start of the treatment. Survival at 168 h (7 days) after treatment initiation gave a good estimate of genotypic tolerance to heat stress with 48-h heating (Fig. 3). With continuous heating, best differentiation among genotypes was found after 78 or 96 h.

It was encouraging to note that some of the breeding lines had tolerance equal to that of the local control C1VT II (Fig. 3). The fact that others did not, however, clearly indicates that it may be necessary to regularly screen for heat stress tolerance. We are further refining the technique after which we will begin to intensively screen breeding materials.

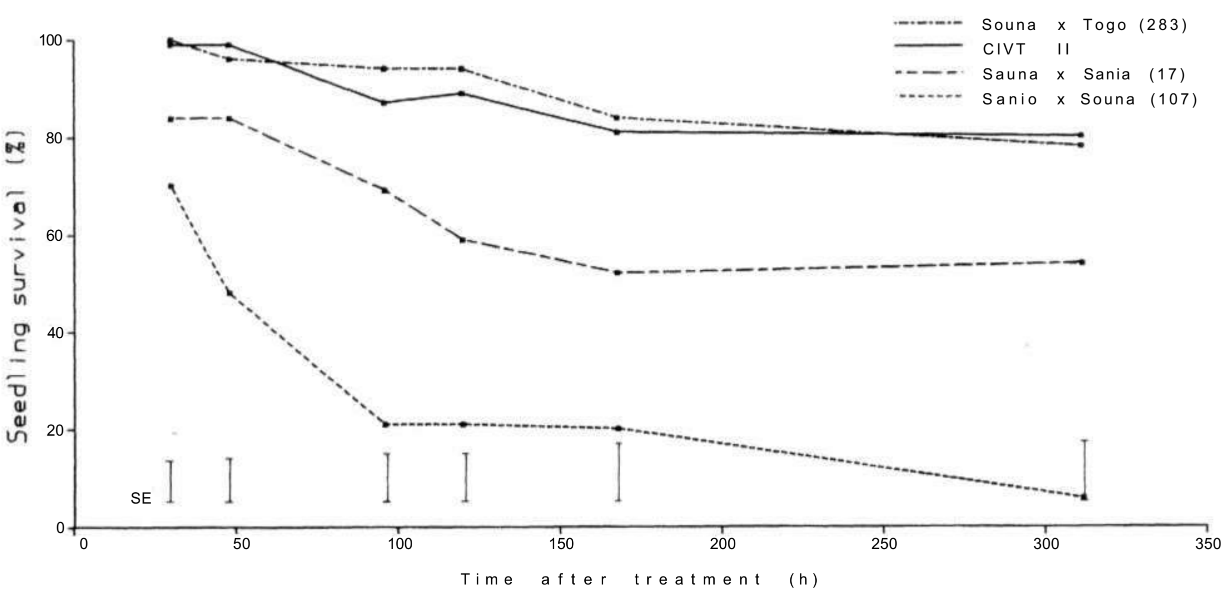


Figure 3. Seedling survival (%) in four selected pearl millet lines at five different times after the initiation of a 48-h period of high (48°) temperature treatment. Vertical bars are SE based on the twenty lines in the test, ISC, 1984.

Yield Compensation Following Pre-flowering Stress

Several reports in the literature indicate that drought stress during early crop growth has little adverse effect on grain yield in pearl millet. We investigated in detail in 1982 the effect of drought stress during the panicle development stage (20 to 48 days after emergence, DAE) using four experimental hybrids.

Drought stress affected the growth and development of the main shoot in all genotypes, reflected in a decrease in main shoot grain yield per unit area (Table I). Flowering was delayed by stress from lack of water in all the genotypes, in both main shoot and tillers, but the effect was more pronounced in the tillers (Fig. 4). Flowering delay in the stress treatment was associated with increased numbers of productive (panicle-bearing) tillers plant^{-1} (Fig. 4).

The decrease in main shoot grain yield was offset by an increased grain yield contribution by the extra tillers. In ICH 220, compensation by tillers exceeded the loss suffered in the main shoot resulting in a significantly higher grain yield under stress conditions (Table 1). ICH 385 and ICH 162 showed no significant reduction in

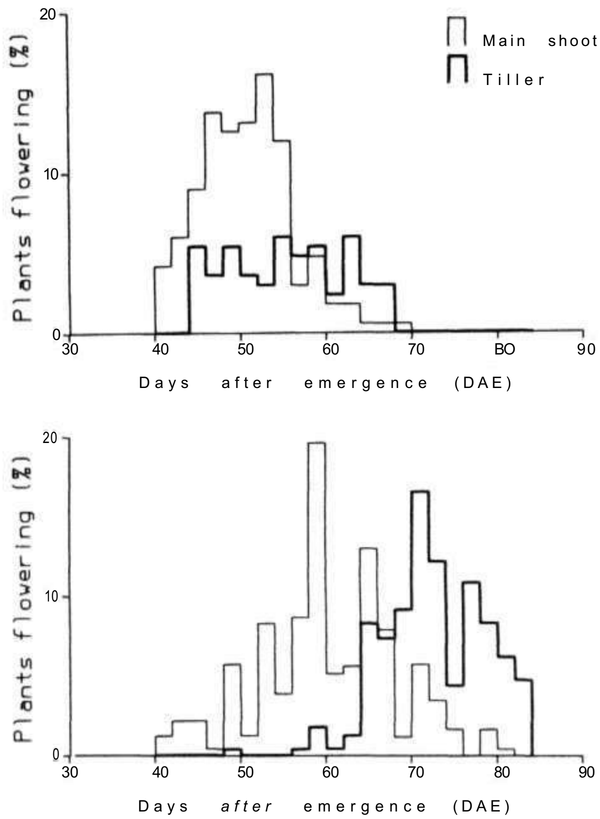


Figure 4. Flowering of main shoot and tiller panicles in ICH 221 in the irrigated (above) and stressed (below) treatments, ICRISAT Center, summer 1982.

Table 1. Mean grain yield, number of grains, and days to 50% flowering in four pearl millet hybrids under two irrigation treatments, ICRISAT Center, summer 1982.

		Grain yield (g m^{-2})		No.of grains m^{-1} (10 000 m^{-2})		
Genotype	Treatment	Main shoot	Tillers	Main shoot	Tillers	Days to 50% flowering
ICH 220	Irrigated	179	84	2.7	1,6	42
	Stressed	136	173	2.0	3.1	44
ICH 226	Irrigated	196	99	2.8	2.0	46
	Stressed	99	127	1.7	2.4	55
ICH 385	Irrigated	177	55	3.1	1.3	44
	Stressed	114	133	2.1	2.7	51
ICH 162	Irrigated	253	19	4.0	0.4	55
	Stressed	224	59	2.9	1.1	68
Mean (Irrigated)		201	64	3.2	1.3	48
Mean (Stressed)		143	123	2.2	2.3	57
SE (Treatment)		±7.3	±12.9	±0.22	±0.20	±0.7

Pearl millet hybrid ICH 220 in the fully-irrigated control treatment (above) and midseason stress treatment (below) 10 days after the stress treatment was terminated. The rapid recovery of the stressed crop is already evident, ICRISAT Center, 1984.

grain yields in the stress treatment, but in ICH 226 main shoot grain yield loss was only partially compensated by tillers, resulting in overall reduced grain yields in the stress treatment.

Since stress was terminated prior to flowering, individual grain mass was not affected. The compensation for the grain yield losses suffered by the main shoot due to stress was therefore derived entirely from the grain number component of the tillers in all genotypes (Table 1).

The increased tiller grain numbers reported in Table 1 could be a result of: increased proportion of productive tillers; increased grain number on a tiller panicle; or a combination of the two.

Since it was difficult to separate these effects in the pooled tiller harvest in 1982, we examined this question in a subsequent experiment in 1983, in which the individual tiller (T) yields and yield components were measured separately.

Main shoot grain yield was reduced by stress but the grain yield of the tillers again increased, resulting in similar yields in the two treatments. The compensation in grain yield was mainly due to an increase in the number of tillers producing an inflorescence at the T, and T_2 positions (Table 2), and not to an increase in the higher order tillers, suggesting a reduction in main shoot dominance by stress. Changes in the grain number panicle^{-1} were small and generally not significant (Table 2).

These experiments indicate that although stress in the early crop growth stage has no adverse effect on overall grain yield, it does affect the relative contribution of the main shoot and tillers. Pearl millet has the capacity to compensate for a reduction in grain yield from the main shoot due to stress during panicle development, by increasing the number of tillers that produce a panicle.

Biotic Stresses

Diseases

Downy Mildew *(Sclerospora graminicola)*

Effect of temperature on germination of sporangia. Suggestions that differences in effectiveness of inoculation with *Sclerospora graminicola* sporangial suspension might be due to effects of temperature on germination and infection were investigated. Sporangia were suspended in water and incubated at 10, 15, 20, 25, 30, 35,40, and 45° C. At 30-min intervals and

Table 2. Number of panicles plant^{-1}, grain yield plant^{-1}, and number of grains panicle*^{1} by shoot (main and tillers 1-5) and total plant'^{1} in pearl millet hybrid ICH 220 under two irrigation treatments, ICRISAT Center, summer 1983.

Treatment	Main shoot	Tiller number				Total plant^{-1}	SE
		1	2	3	4-5		
		No. of panicles plant^{-1}					
Irrigated	1.00	0.58	0.27	0.16	0.14	2.15	± 0.043
Stressed	1.00	0.87	0.52	0.31	0.20	2.90	± 0.052
		Grain yield (g plant^{-1})					
Irrigated	10.88	4.43	1.98	0.54	1.24	19.1	± 2.36
Stressed	8.49	5.61	2.89	1.39	1.00	19.4	±4.01
		Grains panicle^{-1}					
Irrigated	1661	1372	1417	694	899	3130	±262
Stressed	1248	1141	1075	923	765	3150	±233

for up to 3 h, a portion of each sporangial suspension was removed, a few drops of lactophenol were added to arrest sporangial germination (zoospore release) and then the sample was microscopically examined to quantify sporangial germination. Germination began during the first 30-min, with the highest frequency at 40 and 45°C. There was a general increase in germination during the first 1.5-2 hat all temperatures, except 40 and 45° C where little germination occurred after the first 30 min of incubation (Fig. 5). The results suggest that in a field situation, sporangial germination occurs over a wide range of temperatures provided free water is available.

Effect of temperature on germtube elongation. To study the effect of temperature on the rate of germtube elongation, we examined a dilute suspension of viable zoospores on a haemacytometer slide, and noted the location of isolated, but encysted zoospores. The slides were then incubated at six temperatures: 10, 15, 20, 25, 30, and 35°C. Germtube length was measured at hourly intervals by briefly removing the slides from the incubator and microscopically measuring the lengths of germtubes emanating from the identified zoospores. Germination and germtube growth occurred at all temperatures, and germtubes continued to elongate throughout the test period. The germtubes grew faster at 30°C (Fig. 6). Given free water, zoospores could probably germinate and germtubes elongate over a wide range of temperatures in the field.

Studies on pathogenic variability in *S. graminicola.* In a study at the University of Reading, UK, on an ICRISAT / Overseas Development Administration (ODA)/ University of Reading collaborative project, 10 pearl millet cultivars from India and countries in Africa were tested for their reactions to 12 isolates of *S. graminicola angustatus* from Burkina Faso, India, Niger, Nigeria, and Senegal. The downy mildew (DM) reaction of most hosts varied proportionally to the virulence of the isolates. However, stable resistance was found in line 111 B, originally from Ludhiana, India, which had recently undergone two cycles of selection for resistance in the DM nursery at ICRISAT Center, and in a Souna accession from Cinzana, Mali.

A single isolate of *S. graminicola* from Zambia had a pathogenicity pattern that

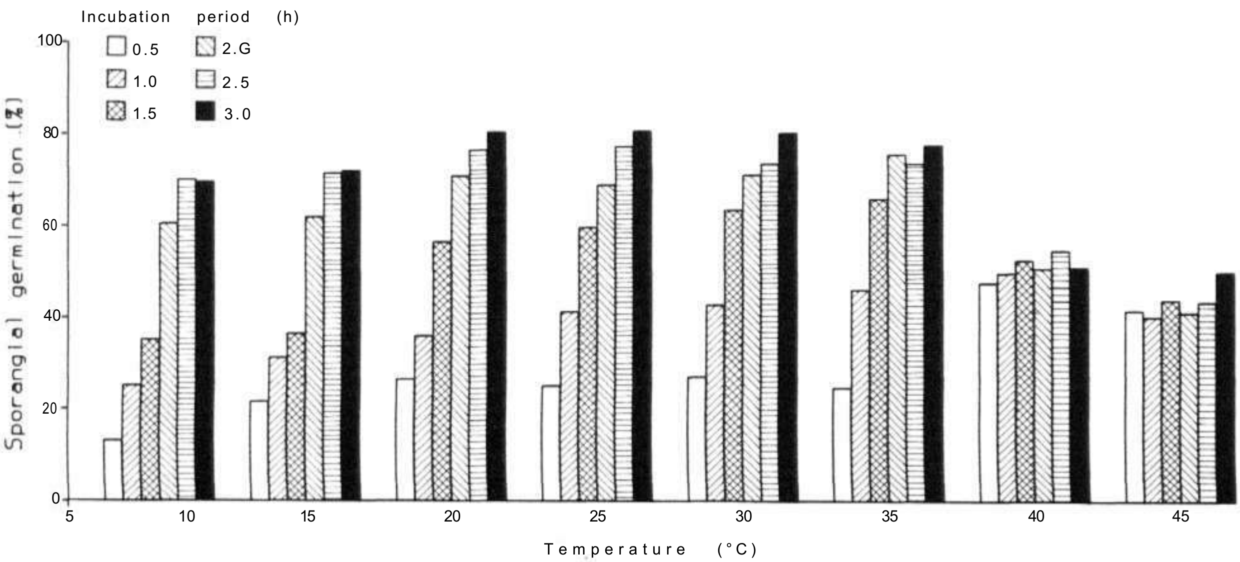


Figure 5. Effects of temperature and incubation period on germination of *Sclerospora graminicola* sporangi suspended in water, ICRISAT Center, 1984.

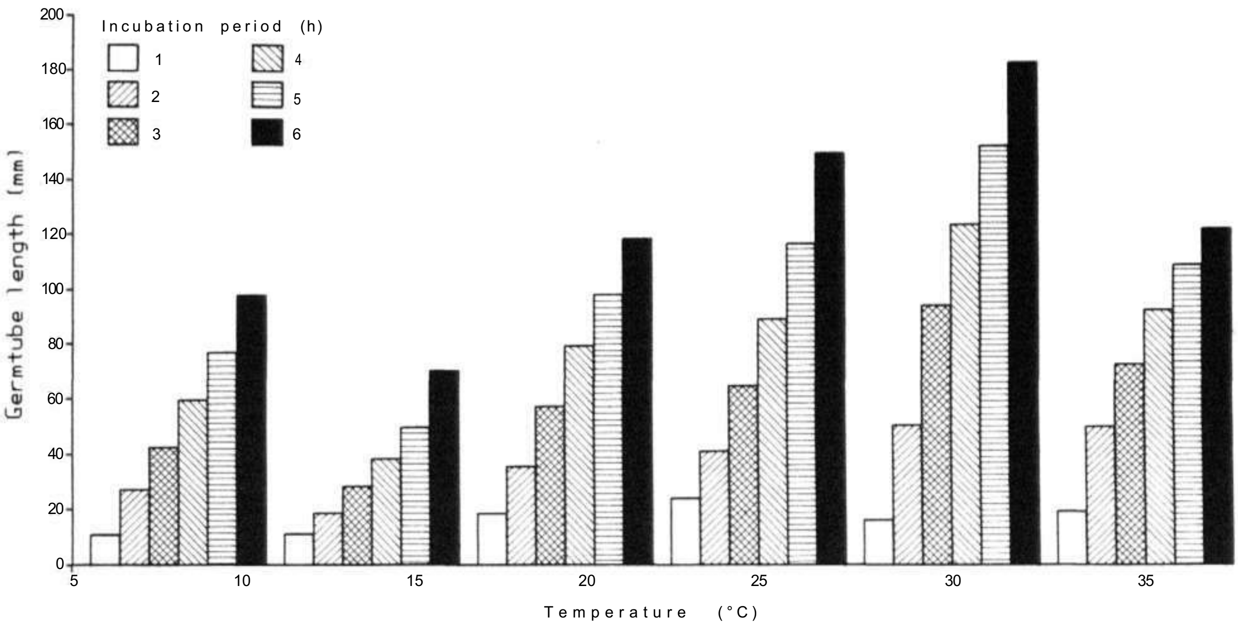


Figure 6, Effects of temperature and incubation period on the germtube length *(um)* **of zoospores of** ***Sclerospora graminicola*** **suspended in water, ICRISAT Center, 1984.**

resembled those from India more than those from West Africa. However, unlike the Indian isolates used in this test, the Zambian isolate did not cause the stunting of plant growth in the Indian hybrid, BJ 104.

Screening for resistance at ICRISAT Center. From 1976 to 1982, 3163 germplasm accessions originating from more than 20 countries in the major millet-growing areas of the world, were screened for resistance to DM at ICRISAT Center. A total of 428 accessions with high levels of resistance, and that flowered in 45 to 60 days, were further evaluated this year; from these we made 48 single-plant selections having resistance and some form of agronomic eliteness. Progeny of these were resistant, and typically 110 to 200 cm tall, with earhead lengths of 15 to 65 cm; the mass of a thousand grains varied from 5-10g. The selections will serve as our major sources of DM resistance for breeding in the coming years.

Multilocational testing. The 45-entry International Pearl Millet Downy Mildew Nursery (IPMDMN) was sent to 12 cooperators in India and one in Senegal. Data were received from six Indian locations. The highest DM pressure was recorded at Mysore followed by ICRISAT Center. No entry was DM-free at all locations. However, there were 32 entries that developed <10% DM at all locations. These included P 7-4, P 24, P 310-17, P 472, 70512-3, and SDN 503-12, that had also shown high degrees of stable resistance in previous years. We now have more than 35 entries that have shown stable DM resistance for 2 to 9 years. Five of these were named by the Plant Materials Release Committee in 1984. We supplied seed of DM-resistant lines to several breeders in India for use in their breeding programs.

Ergot *(Claviceps fusiformis)*

Resistance mechanism. Investigations into the structure of pearl millet stigma and the sequence of events during pollination conducted at Imperial College, London, under an ICRISAT/ODA project, have provided a basis

Downy mildew (DM) susceptible (left) and resistant (right) selections from a highly susceptible line, 7042, in DM screening nursery, ICRISAT Center, 1984.

for understanding the mechanism of ergot resistance in selected pearl millet lines.

Pearl millet stigmas possess a specialized zone of cells located within the fused region of the stigma which collapse in response to compatible pollination. When pollination preceeds infection, constriction effectively prevents the ergot fungus from gaining access to the ovary. Parallel studies on the path of entry of the pathogen have shown that *C.fusiformis* hyphae have the ability to mimic pollen, thereby entering the ovary directly through the stigma. Passage of hyphae through the sensitive constriction zone similarly induces stigma collapse (Fig. 7).

Resistant lines showed greatly reduced protogyny (interval between stigma emergence and anthesis). Self-pollination occurs readily in such lines, which leads to rapid stigma-withering, thus preventing ergot infection.

Screening for resistance. During the summer and rainy seasons we screened more than 3800 entries for ergot resistance at 1CRISAT Center and Aurangabad, in a continuous process of identifying, verifying, and using sources of resistance.

Identifying resistance. To identify new sources of resistance, we screened about 400 DM-resistant germplasm accessions originating mainly from Cameroon, India, Niger, Nigeria, Senegal, and Sudan in the ICR1SAT multiple disease nursery by inoculating 5-10 plants per entry. Most entries were highly susceptible (>30% ergot severity) and only 21 single heads

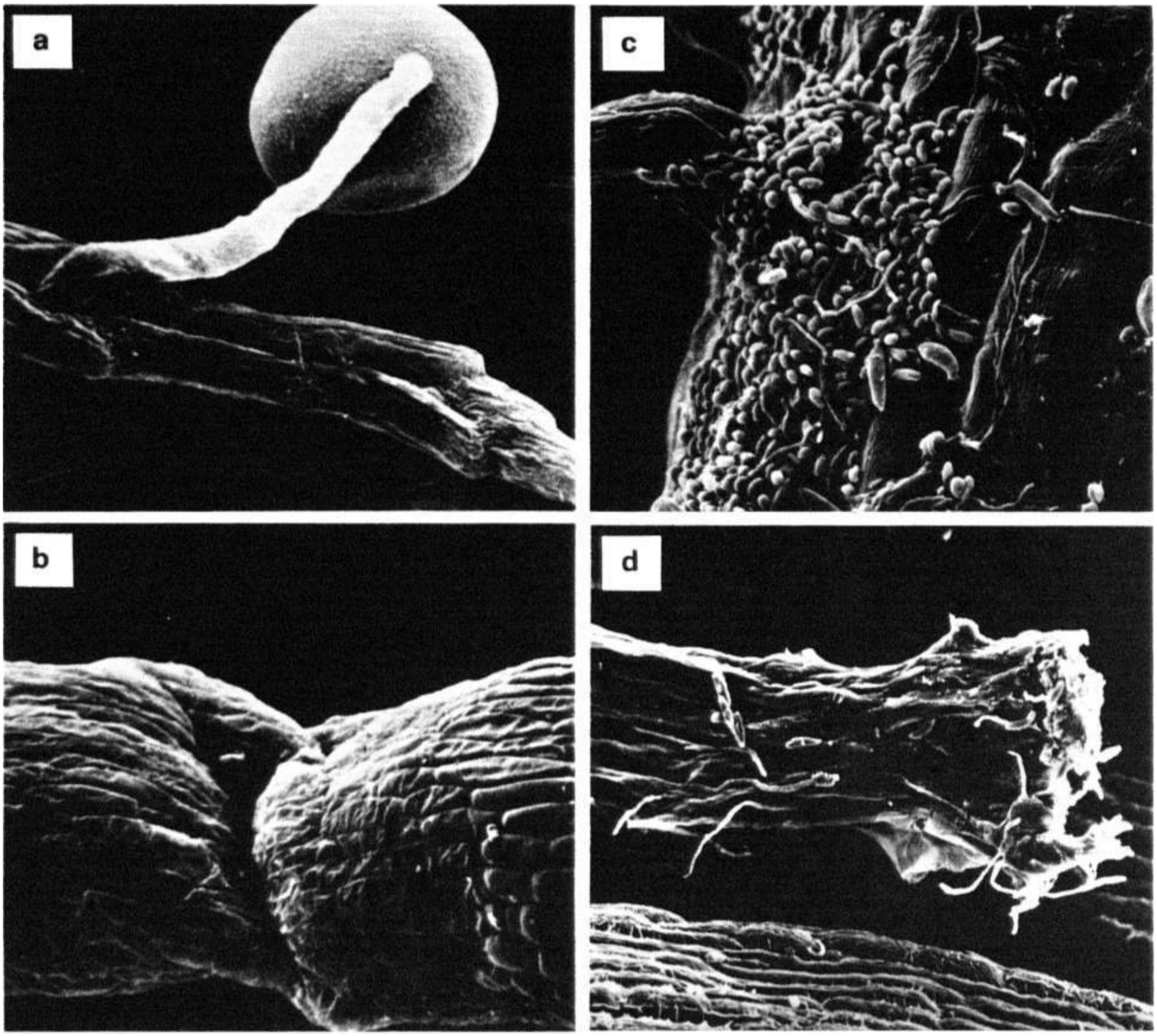


Figure 7. Scanning electron micrographs of pearl millet stigmatic tissue and interaction with pollen and the ergot fungus (*Claviceps fusiformis*). a. Germinating millet pollen penetrating a stigmatic trichome 30 min after pollination (x350). b. Postpolhnation constriction of stigmatic tissue 6 h after pollination (x350). c. Germinating microspores and macrospores on the stulodial axis 14h after inoculation (x200). d. Constriction of stigmatic tissue following penetration and growth by the ergot fungus (x100), ICRISAT Center, 1984.

from plants showing resistance to DM, ergot, and smut were selected for further evaluation.

Multilocational testing. The 32-entry 1984 International Pearl Millet Ergot Nursery (IPMEN) was tested at seven locations in India. Although no entry remained ergot-free at all locations, 11 showed across-location mean infection severity of not more than 1%; 9 had between 2 and 5%, and the remaining 8 had between 6 and 13% compared with 44-61% on the susceptible controls. Ergot-resistant lines produced at ICRISAT Center (ICMPE and ICMPES numbers) have shown high levels of resistance across locations in Nigeria and India for 2-3 consecutive years (Table 3). These lines have also shown resistance to DM, smut, and rust in the multiple disease nursery at ICRISAT

Table 3. Mean performance often International Pearl Millet Ergot Nursery (IPMEN) entries at Samaru, Nigeria, and six Indian locations, rainy seasons 1982 to 1984.

Entry[1]	Ergot severity (%)[2] at 7 locations[3]							Other diseases at ICRISAT Center		
	1	2	3	4	5	6	7	DM incidence (%)	Smut severity (%)[4]	Rust severity (%)[5]
ICMPE 134-6-25		1	<1	<1	1	1	<1	2	0	15
ICMPE 134-6-34		1	1	<1	1	2	1	3	0	15
ICMPE 13-6-27	3	1	1	1	4	2	2	0	0	12
ICMPE 13-6-30		1	2	1	1	3	2	2	0	10
ICMPES 1	<1	1	1	1	2	2	1	2	0	7
ICMPES 2	1	2	1	<1	5	2	2	2	0	15
ICMPES 23	<1	2	2	<1	3	3	1	1	0	2
ICMPES 27	<1	1	1	<1	1	1	1	3	0	5
ICMPES 28	<1	5	3	1	7	1	6	<1	0	5
ICMPES 32	1	16	4	2	8	2	1	2	0	5
Susceptible control	86	89	91	45	54	64	44	35	63	82

1. ICMPE(S) = ICRISAT millet pathology ergot-resistant lines (sib-bulk).
2. Based on 20-40 inoculated inflorescences per entry in 2 replications each year.
3. Locations: 1 = Samaru, 2 = Aurangabad, 3 = ICRISAT Center, 4 = Jamnagar, 5 = Mysore, 6 = Ludhiana, 7 - New Delhi.
4. Based on 1982 and 1983 testing.
5. Based on 1983 and 1984 testing.

Center. Stability of multiple disease resistance in these lines needs to be verified across a range of environments in Africa and India.

Developing resistance. We continued the development of ergot-resistant lines with emphasis on concentrating resistance genes from diverse sources and selecting progenies with desirable agronomic traits. Crosses were made among ergot-low susceptible (ELS) plants of selected germplasm accessions from Ghana, India, Nigeria, and Togo, to generate 102 F_1 lines. We screened more than 3000 entries in F_1 to F_8 generations and selected 862 single plants from 121 lines with high ergot resistance (<5% severity) and desirable agronomic traits.

Eighteen ergot-resistant sib-bulk (ICMPES) lines which were developed for high ergot resistance and improved agronomic traits were evaluated multilocationally for grain yield and in the ICRISAT multiple disease nursery for disease reaction. Several of the ICMPES lines had equal or better yields than the high-yielding controls, WC-C75 and ICMS 7703, and showed high resistance to DM, smut, and rust in addition to ergot (Table 4). However, some were noticeably photoperiod sensitive when grown in North India.

Utilizing resistance. We continued efforts to transfer resistance into hybrid seed parents. A large number of progenies from crosses between ICP 220 and ergot-resistant (ER) line, J104 and ER line, and 5054 B and ER line were screened at F_2, F_3, $BC_1(F_1)$, and $BC_2(F_1)$ generations and ER segregants were selected. Results so far indicate that with the backcross method it should be possible to transfer ergot resistance to hybrid parents.

Ergot-resistant ICMPES lines which have shown improved agronomic traits will be utilized to constitute an ER composite from which we hope to be able to produce ER experimental varieties. Seed of ER lines were

Table 4. Mean grain yield (kg ha^{-1}) and disease reactions of 18 pearl millet ergot-resistant sib-bulks (ICMPES), at seven Indian locations, 1984.

	Grain yield (kg ha^{-1}) at locations[1]								Disease reactions			
Entry	1	2	3	4	5	6	7	Mean	Ergot sev (%)[2]	DM incidence (%)	Smut sev. (%)	Rust sev. (%)
ICMPES 8	2830	2790	1290	2240	2410	1800	2080	2210	< 1	0	0	5
ICMPES 28	2420	2810	850	3160	2320	1520	2130	2170	0	0	0	5
ICMPES 29	2320	2540	1180	3130	2130	1210	1860	2050	0	0	0	5
ICMPES 32	2380	1640	1310	2410	2060	1670	2300	1970	1	0	1	5
ICMPES 9	2570	1850	960	3450	1460	1200	2100	1940	1	1	0	40
ICMPES 34	2260	2980	1520	1780	1490	1980	1520	1930	0	0	<1	15
ICMPES 5	2200	2700	1080	1870	1420	990	1720	1710	0	5	0	40
ICMPES 6	2820	1820	1010	1820	1740	1020	1720	1710	<1	0	0	5
ICMPES 36	2370	2640	1120	1460	1250	1180	1550	1650	0	0	2	10
ICMPES 22	2080	1510	1180	2070	1700	1190	1660	1630	0	1	<1	15
ICMPES 16	2120	1630	1070	1870	1610	1000	2010	1610	0	0	0	10
ICMPES 35	2090	2070	1100	1460	1490	1340	1680	1600	0	0	<1	5
ICMPES 7	2540	1760	1140	1870	1240	1410	1160	1590	<1	6	0	5
ICMPES 30	2280	1680	1120	2190	1630	840	970	1530	0	0	<1	5
ICMPES 31	I960	1580	1160	2150	1420	560	1450	1470	< 1	0	0	5
ICMPES 18	2200	1090	1220	2070	1210	820	1230	1410	0	1	0	5
ICMPES 24	2120	1230	910	1650	930	380	1320	1220	0	1	0	10
ICMPES 19	2200	1140	720	1160	990	360	1010	1080	0	0	0	5
Controls												
WC C75	2420	2390	1150	1040	2270	1930	2390	1940	45	0	29	25
ICMS 7703	1940	2840	1420	1300	2590	2010	2450	2080	44			
SE	±198	±370	±120	±353	±220	±140	±201	±229				
Location mean	2310	2040	1130	2010	1670	1220	1720	1730	4	1	2	12
CV (%)	17	31	18	30	23	20	20	23				

1. Locations; 1 = ICRISAT summer; 2 = ICRISAT high fertility (80N: 18P); 3 = ICRISAT low fertility (40N:9P); 4 = ICRISAT ergot nursery; 5 = Aurangabad; 6 = Pune; 7 = Bhavanisagar.
2. Based on open-head inoculation.

supplied to several breeders in India for use in their resistance breeding programs. Four bulks with stable resistance to ergot were named by the Plant Material Release Committee of ICRISAT in 1984.

Smut (*Tolyposporium penicillariae*)

Screening for resistance. We screened about 3100 entries for smut resistance at ICRISAT Center and Hisar, in the process of identifying, verifying, and utilizing sources of resistance.

Identifying resistance. To identify new sources of resistance we screened the same set of more than 400 DM-resistant germplasm accessions which were screened for ergot in the multiple disease nursery by inoculating 5-10 plants with smut inoculum in each entry. Most entries were highly susceptible and the common 21 single heads from plants that showed resistance to DM, ergot, and smut were selected.

Multilocational testing. The 32-entry 1984 International Pearl Millet Smut Nursery

Pearl millet ergot screening nursery at ICRISAT Center. Resistant genotypes (left) have clean earheads, compared to susceptible genotypes (right) that have black sclerotia on the earheads.

(IPMSN) was tested at four locations in India. The mean smut severities of the 28 test entries varied from 0 to 6% compared with 44 to 52% on the susceptible controls. The smut-resistant sib-bulks (ICMPS numbers), recently produced at ICRISAT Center, showed very high levels of smut resistance (0-3% severity) across three Indian locations over 2 to 3 years (Table 5). These lines were also resistant at Bambey, Senegal; Samaru, Nigeria; and Sadore, Niger in 1983 (the nursery was not conducted at these locations in 1984). In addition to smut resistance, these lines have shown moderate to high levels of resistance to DM in India.

Developing resistance. We continued efforts to produce smut-resistant (SR) lines with desirable agronomic traits. We screened 512 entries in the F_1 to F_4 generations from crosses among SR germplasm accessions, SR F_6 lines, and DM-resistant lines and selected 104 entries which showed high smut resistance and improved agronomic traits. We evaluated 1626 F_4 to F_6/S_6 SR entries for agronomic traits during the rainy season at ICRISAT Center and together with the breeders, selected 118 agronomically-desirable lines.

We evaluated 12 ICMPS lines for grain yield and disease reaction at various locations in India during the 1984 rainy season. Several lines had similar or higher yields than either of the controls, WC-C75 and ICMS 7703, at individual locations. In addition to having high resistance to smut, these lines were resistant to DM across locations (Table 6).

Table 5. Mean smut severity[1] (%) and downy mildew incidence (%) of the best new smut-resistant pearl millet line-bulks (ICMPS) evaluated at three Indian locations, 1982 to 1984.

	Locations									DM incidence (%)[2]	
	Hisar			Jamnagar			ICRISAT Center				
	Year			Year			Year				
Entry	82	83	84	82	83	84	82	83	84	83	84
ICMPS 100-5-1	0	0	0	<1	0	0	0	0	0	<1	1
ICMPS 200-5-5-5	-[3]	0	<1	-	0	0	-	0	0	<1	1
ICMPS 700-1-5-4	-	0	<1	-	0	0	-	0	0	1	<1
ICMPS 900-1-4-1	-	0	3	-	0	0	-	0	0	<1	2
ICMPS 900-3-1	-	0	<1	-	0	0	-	0	0	<1	1
ICMPS 900-9-3	0	0	0	<1	0	0	0	0	0	1	3
ICMPS 1300-2-1-2	-	0	<1	-	0	0	-	0	0	0	4
ICMPS 1400-1-6-2	-	0	<1	-	0	0	-	0	0	<1	2
ICMPS 1500-7-3-2	-	0	0	-	0	0	-	0	0	<1	1
ICMPS 1600-2-4	<1	<1	1	0	0	0	0	0	0	3	1
ICMPS 1800-3-1-2	-	<1	<1	-	0	<1	-	0	<1	<1	1
ICMPS 2000-5-2	<1	<1	<1	<1	0	0	<1	0	0	1	1
Susceptible control	36	78	72	58	44	43	72	82	74	25	49

1. Mean severity based on 20-40 inoculated heads in 2 replications.
2. Mean of 4 locations, Gwalior, Hisar, Jamnagar, and ICRISAT Center.
3. Entries not included.

Utilizing resistance. We screened 1780 S, progenies from the Smut-Resistant Composite (SRC) and the Inter-Varietal Composite (IVC) populations. Two experimental varieties, ICMV 82131 and ICMV 82132, derived from the SRC, and two SR synthetic varieties, ICMS 8282 and ICMS 8283, found promising for grain yield in breeding trials during 1983 showed high levels of resistance to smut and DM in the 1984 IPMSN at four Indian locations. The frequency of resistance in IVC was approximately 30% (determined from screening 920 S_1 progenies). Progenies with a good level of smut resistance (<5% severity) were selected for recombination.

Smut resistance from several ICMPS lines will be introgressed into these composites to increase their levels of smut resistance and agronomic eliteness.

Seed of SR lines were supplied to several breeders in India for their resistance breeding programs. Six lines with stable resistance to smut were named by the Plant Material Release Committee of ICRISAT in 1984.

Rust (*Puccinia penniseti*)

Screening for resistance. A total of 888 entries including germplasm accessions, hybrid parents, populations, ergot- and smut-resistant lines-/populations, and entries from the All India Coordinated Millets Improvement Project (AICMIP) trials and nurseries were evaluated for rust resistance at Bhavanisagar. Of these, 175 entries were rust-free and 287 others developed <10% rust infection. The remaining entries were moderate to highly susceptible to rust.

Seventeen DM-resistant hybrids, produced using DM-resistant versions of 5141A and J104, were evaluated for their reaction to rust, but none of these hybrids showed an acceptable level of rust resistance.

Table 6. Grain yield (kg ha^{-1}) and disease reactions of 12 pearl millet smut-resistant line-bulks (ICMPS) and the two controls at seven Indian locations, 1984.

Entry	Grain yield (kg ha^{-1}) at locations[1]								Disease reactions	
	1	2	3	4	5	6	7	Mean	Smut[2] (%)	DM[3] (%)
ICMPS 100-5-1	1250	1590	2070	2670	1900	1690	1910	1870	0	0
ICMPS 1100-2-1-3	1820	1570	1720	2640	1250	1920	1650	1790	1	2
ICMPS 1300-2-1-2	1220	1650	2570	2240	1070	1860	1900	1790	0	0
ICMPS 900-3-1	1700	1640	1910	1720	1490	1850	2020	1760	0	2
ICMPS 1600-2-4	1640	1760	2040	2150	650	2090	1940	1750	0	0
ICMPS 700-1-5-4	1430	1390	1710	2510	980	2140	1750	1720	0	0
ICMPS 1800-3-1-2	980	1640	1420	2150	1300	1680	2280	1640	2	0
ICMPS 1500-7-3-2	960	1580	1530	1990	1760	1610	1620	1580	0	0
ICMPS900-1-4-1	1020	1700	1660	1350	1790	1220	1800	1510	0	2
ICMPS 1700-1-1-1	1280	1400	1970	1650	1180	1380	1510	1480	<1	2
ICMPS 200-5-5-5	1410	1380	1490	1310	1530	1290	1890	1470	0	0
ICMPS 2000-5-2	700	860	1860	1860	780	1550	1610	1320	0	0
Controls										
WC-C75	1590	2220	3170	2570	2000	2140	2270	2280	23	2
ICMS 7703	2040	1610	2480	3110	1450	2030	2090	2110	25	0
SE	±190	±160	±180	±300	±180	±240	±188	±205		
Location mean	1360	1580	1970	2140	1370	1750	1870	1720		
CV (%)	25	18	16	25	23	24	18			

1. Locations: 1=Aurangabad, 2=Bhavanisagar, 3=ICRISAT high fertility (80N: 18P), 4=Hisar, 5=ICRISAT low fertility (40N: 9P), 6=ICRISAT smut nursery (all rainy season trials), 7=ICRISAT dry season.
2. Mean severity from Hisar and ICRISAT Center.
3. Mean incidence from Hisar, ICRISAT Center, Bhavanisagar, and Aurangabad.

Inheritance and utilization of rust resistance. With ICRISAT pearl millet breeders, we studied the inheritance of a hypersensitive type of resistance to rust in two pearl millet lines derived from IP 2696, a germplasm accession from Chad. The two lines were crossed onto two susceptible, male-sterile lines, 1108A and 81A. Plants in the F_1, F_2, BC_1, and BC_2 generations were grown under high rust pressure at ICRISAT Center, Bhavanisagar, and Kovilpatti. The two IP 2696-derived lines and all plants in the F, generation were rust-free at all three locations. F_2 plants fit a 3:1 resistant:susceptible ratio, and progeny of the backcrosses to the susceptible male steriles fit a 1:1 resistant:susceptible ratio. These results indicate that the resistance identified is conferred by a single dominant gene, and susceptibility by its recessive allele. Symbol Rppl has been proposed for the resistant gene and rppl for the susceptible gene.

In India, rust is often most severe during the off-season when hybrid seed is produced; rust resistance in the seed parents (male-sterile lines) should reduce losses of valuable hybrid seed. Resistance is therefore being incorporated into three male-sterile lines, 843A (ICMA 2), 81A (ICMA 1), and 5141A.

Multilocational testing. A 45-entry International Pearl Millet Rust Nursery (IPMRN) was evaluated at six locations in India. Rust was most severe at Bhavanisagar and moderate at other locations. No entry was rust-free at all locations; however, one entry, P 1564, was free at all locations except Ludhiana where <5% rust was recorded in one block. Several other entries including IP 6138-3, P 1592, P 1581, and P 548 also showed good levels of resistance. Six lines with stable resistance to rust were named by the Plant Material Release Committee of ICRISAT in 1984.

Multiple Disease Resistance

We screened 614 entries for multiple disease resistance (DM, ergot, smut, and rust) during the 1984 rainy season at ICRISAT Center. The entries included were from hybrid and population trials of the AICMIP, selected germplasm accessions from Africa and India, and entries of the 1984 IPMDMN, IPMEN, and IPMSN. Among the AICMIP entries, 94% showed resistance to DM, 2% to smut, and 4% to rust, but none were resistant to ergot (Table 7). A high percentage of germplasm accessions showed resistance to DM and 38% showed resistance to smut. Among the disease nurseries, entries from IPMDMN and IPMSN were resistant to DM and smut but not to ergot. Twenty-four of the 28 IPMEN entries showed resistance to all the four diseases.

We also evaluated 48 agronomically elite single-plant selections from germplasm accessions that were resistant to DM, for their reaction to rust. Twenty-one selections developed no rust and all others, except two, developed <10% rust. All but one of the 21 selections are from countries in West Africa. These selections are good sources of resistance to both DM and rust.

Seed of lines with resistance to more than one disease were supplied to breeders in India for their disease-resistance breeding programs. Four lines with combined stable resistance to DM, ergot, and smut were named by the Plant Material Release Committee of ICRISAT in 1984.

Table 7. Pearl millet lines screened for multiple disease resistance, ICRISAT Center, rainy season 1984.

Trial/Nursery	Entries screened	Entries found resistant (<10%) to			
		DM	Ergot	Smut	Rust
AICMIP					
Hybrids and populations	92	89	0	2	3
A and B lines	26	22	0	0	2
Germplasm accessions	395	380	2	152	1
IPMDMN	45	40	0	19	-
IPMSN	28	28	1	28	2
IPMEN	28	28	25	28	24
Total	614	587	28	229	32

Research at the ISC

As a pathologist was not present at the ISC during most of the year, very little data on millet diseases was obtained. DM incidence was generally low in breeding plots, although the highly-susceptible line, 7042 showed high levels of DM infection at maturity in sequential plantings made early in the rainy season.

DM levels were high in some breeding materials grown during the January to May off-season nursery. Mean DM levels in progenies of four populations ranged from 9 to 29% and 57 to 78% in some selected F_1s of crosses between accessions from Niger and other countries. The male-sterile line 81 A, which has a high level of resistance to DM in India, showed 5% incidence. These observations are important in that they show that the off-season nursery at the ISC might be useful for screening pearl millet under moderate DM pressure.

Insect Pests

Pest surveys

We made surveys in Tamil Nadu, Maharashtra, and Gujarat to improve our understanding of pearl millet pest problems in farmers' fields.

Shoot fly (*Atherigona approximate),* was the most important and serious pest in Tamil Nadu; it was also present in Maharashtra and Gujarat. Leaf folder *(Marasmia trapezalis),* gray weevil, *(Myllocerus* spp), oriental armyworm *(Mythimna separata),* corn leaf aphid *(Rhopalosiphum maidis),* earhead caterpillars *{Heliothis armigera, Cryptoblabes* spp), stink bug *(Bagrada cruciferarum),* blister beetle *(Cylindrothorax* spp), chafer beetle (*Oxycetonia versicolor),* midge *(Geromyia penniseti),* and head caterpillars were also recorded as serious pests at some locations.

During the reproductive phase, chafer beetle and head caterpillars (*H.armigera* and *Euproctis* sp) were the major pests. Chafer beetles were most active at head emergence while *H. armigera* larvae and damage were recorded 60 to 90 DAE with a peak on 75 day-old plants (37-98 larvae/ 100 earheads). Hairy caterpillar *{Euproctis* sp) larvae were most active on mature earheads (6-13 larvae/100 earheads). The newly released cultivars (WC-C75 and ICMS 7703) were generally less susceptible to different insect species than the commercial hybrids under natural conditions.

Pest Incidence at ICRISAT Center

We recorded pest incidence on four cultivars at ICRISAT Center at fortnightly intervals from June to September 1983 (Table 8). The four cultivars used in these studies involve two commercial hybrids grown in India (BJ 104 and MBH 110), and two varieties developed at ICRISAT Center (WC-C75 and ICMS 7703) and released for cultivation in India. The major objective was to compare the susceptibilities of ICRISAT-bred cultivars with the commercial ones. We observed oriental armyworm damage 30 days after seedling emergence (2-3 larvae/100 plants). Corn leaf aphids damage was quite high on 30-day old plants (128-216 aphids/10 leaf whorls). Shoot bug *(Peregrinus maidis)* was also recorded on 30- to 45-day old plants along with armyworm and corn leaf aphid.

Earhead Caterpillar (*Raghuva albipunctella)*

Incidence and fluctuation. During the summer season, October-June 1983/1984 at the ISC, we carried out monthly soil sampling using a 2 mm sieve for diapausing pupae of earhead caterpillars, *R. albipunctella* in the soil. We found a higher proportion (over 70%) of surviving pupae at lower depths (15-25 cm), while the upper profile contained mostly empty pupal cases. Soon after the rains in May, our June sampling revealed specimens undergoing metamorphosis into adult moths.

R. albipunctella were first recorded in light traps in mid-July. Two population peaks were recorded: one at the end of July and the other in mid-August. Eggs were observed in late July and larval activity in early August. The characteristic spiral damage appeared on millet plants in mid

Table 8. Insect pest incidence on four cultivars of pearl millet, ICRISAT Center, rainy season 1983.

	M. separata (larvae/100 plants)		*R. maidis* (aphids/10 leaf whorls)		*P. maidis* (shoot bugs/10 plants)		*O. vesicular* (adults/100 earheads)		*H. armigera* (larvae/100 earheads)		*Euproctis* sp (larvae/100 earheads)	
Cultivar	30[1]	45	30	45	30	45	60	60	75	90	75	90
BJ 104	3(2.0)[2]	4(2.3)	189(13.4)	17(4.2)	7(2.7)	5(2.4)	1(1.4)	3(1.7)	98(9.9)	39(6.4)	5(2.3)	9(3.2)
MBH 110	3(1.9)	5(2.5)	216(14.5)	23(4.7)	4(2.3)	11(3.4)	2(1.7)	2(1.7)	58(7.6)	48(7.0)	2(1.7)	8(2.8)
WC-C75	3(1.9)	1(1.5)	128(11.3)	31(5.6)	3(1.9)	3(2.0)	7(2.4)	7(2.8)	41(6.5)	28(5.4)	3(1.9)	6(2.4)
ICMS 7703	2(1.8)	2(1.7)	172(13.1)	38(6.0)	4(2.0)	4(2.1)	7(2.8)	4(2.1)	37(6.1)	37(6.2)	11(2.8)	13(2.8)
SE	±(0.25)	±(0.18)	±(0.86)	±(0.80)	±(0.40)	±(0.27)	±(0.65)	±(0.48)	±(0.72)	±(0.35)	±(0.68)	±(0.95)

1. Days after crop emergence.
2. Figures in parentheses are $\sqrt{N+1}$ transformed values.

to late August and was most pronounced in early-maturing varieties.

Biology and ecology. We initiated a study in collaboration with our agroclimatologists on the relationships between soil physical parameters, environmental factors, cessation of pupal diapause, and subsequent adult emergence of *R. albipunctella.* This study involved three parts:

1. A post growing season monthly sampling for pupae.
2. An all-year round daily data collection on soil and atmospheric conditions.
3. Light trap studies of adult moths at emergence.

The proportion of surviving pupae in the soil decreased as the summer season progressed, and at a faster rate in the upper soil profile (0-15 cm) than at the lower depths.

Moths appeared in the light traps 45 days after 20.9 mm rain fell on 31 May. A second rainfall of 16.8 mm occurred on 12 June. There were minor rainfalls between these days, sufficient to maintain soil moisture content at a level favorable for the continued development of the insect. Peak *Raghuva* emergence (end-July and mid-August) occurred when soil temperatures were over 30° C at all depths measured. Soil temperatures below 30°C and a dry spell of 9 days in early August coincided with a decrease in adult moth emergence during the same period.

From this study we conclude that the first major rains are essential to break diapause in *R. albipunctella.* Continued development is, however, dependent on a threshold of soil moisture content, and subsequent adult emergence may be related to favorable soil temperatures.

Stem Borer (*Acigona ignefusalis*)

Incidence and fluctuation. We monitored incidence and fluctuation in populations of *Acigona ignefusalis* monthly throughout the year at the ISC, using the stem-splitting technique (100 stems $sample^{-1}$) for larvae, and light traps for adult moths during the cropping season.

Borer incidence was lower in 1984 than in 1983 (Fig. 8). Populations of diapausing larvae at the onset of the season were also considerably lower: 29/100 stems in May 1983 and 14/100 stems in May 1984. Rainfall was also much lower in 1984. Our observations also show a gradual decrease in numbers of diapausing larvae from October to March (Fig. 8), with a sudden drop thereafter as temperatures rise in April. Adult moths were first recorded in light traps in early June with larvae appearing in stems later in the same month. Two borer generations were observed with peaks in mid-July and mid-September.

Our studies involving three sowing dates conclusively indicated higher levels of borer damage on late-sown millet. This trend was not affected by the low borer populations in 1984. A higher level of internode damage was recorded at a much earlier growth stage in the late crop than in the early crop. For example, on Sadore Local sown 1 June, we recorded 45% stem infestation and 6% internode damage on 10 September, 103 DAS; while on a crop sown 30 June we recorded 95% stem infestation and 27% internode damage on 12 October, 104 DAS.

Microbial Associations

Biological Nitrogen Fixation

Nitrogen Balance Studies

In a long-term nitrogen-balance trial started in 1980, four millet cultivars (Table 9) are grown each year in the same plots with the same rates of added nitrogen. During the 5th year (rainy season 1984) the millet cultivars had different N response curves with total dry-matter yields increasing significantly ($P<0.01$) with applied N. We recorded the highest mean dry-matter yield (3260 kg ha^{-1}) from millet cultivar Ex-Bornu across the nitrogen levels and a mean yield of 3350 kg ha^{-1} across cultivars with 40 kg N ha^{-1}. Without applying any nitrogen, Ex-Bornu yielded 2590 kg ha^{-1} total dry matter during this season.

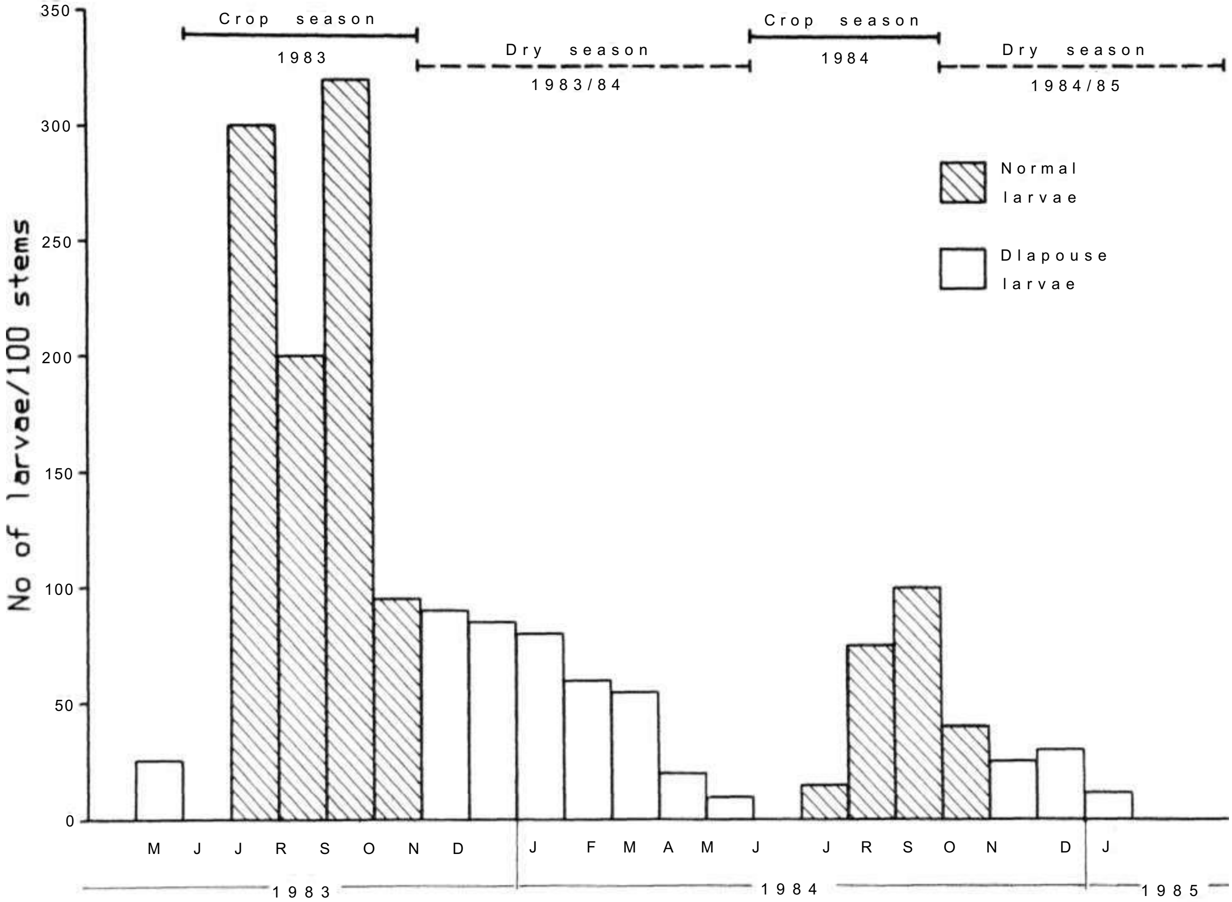


Figure 8. Seasonal fluctuation of *Acigona* larvae, Sadore, 1983-1985.

Table 9. Total dry-matter yield (kg ha^{-1}) of pearl millet cultivars in the 5th season of a long-term, nitrogen-balance trial, ICRISAT Center, rainy season 1984[1].

	N applied (kg ha^{-1})			
Cultivar	0	20	40	Mean
BJ 104	1880	2720	3620	2740
Gam 73	1700	2260	2830	2260
700256	1710	2630	2930	2420
Ex-Bornu	2590	3170	4030	3260
SF		±207		±117
Mean	1970	2700	3350	
SF		±111		
CV(%)		15		

1. Mean of 4 replications. Net area harvested 21 m^2. A basal dose of 9 kg P ha^{-1} was applied.

In our irrigated, long-term nitrogen-balance trial, 65 tropical grasses have been grown for 7 years without the addition of nitrogenous fertilizer. Maximum dry-matter production (37 100 kg ha^{-1} including 2752 kg N ha^{-1}) was obtained by a hybrid, *Pennisetum americanum x P. purpureum* (NB 21), over the 7-year period. Several other grasses, including millet x napier grass hybrids, also produced high dry-matter yields, but *Pennisetum rupellii* produced only 42 000 kg ha^{-1}, including 312 kg ha^{-1} N during the 7-year period of the experiment.

Responses to Inoculation with Nitrogen-fixing Bacteria

In a field trial during the rainy season at ICRISAT Center, we compared the effects of inoculating four millet cultivars with several strains of nitrogen-fixing bacteria. We observed a significant ($P=<0.05$) grain yield interaction between the host cultivars and bacterial strains (Table 10). Inoculation significantly *(P=<0.05)* increased yields in BJ 104 by 30.3% with ICM 1001 and by 33.5% with ICM 2001. Similarly, a significant ($P=<0.05$) increase in the grain yield of ICMS 7703 occurred in the treatments inoculated with A. *lipoferum* (ICM 1001), *A. chroococcum* (ICM 2001), *A. brasilense* (2) and a mixture of *A, brasilense* (1 and 2) over the noninoculated control. Two other millet cultivars, WC-C75 (ICMV 1) and BK 560 did not respond. We observed trends similar to that of grain yield for total dry-matter production by millet cultivars.

In another field trial, at Bhavanisagar, with the same four millet cultivars during the 1984 rainy season, significantly higher *(P=<0.05)* grain yields across cultivars were found in inoculation treatments with *A. lipoferum* (ICM 1001) and *A. brasilense* (SI 33). WC-C75 inoculated with *A, lipoferum* (ICM 1001) gave the maximum increase (33%) in grain yield over the noninoculated control (Table 11).

Table 10. Grain yield (kg ha^{-1}) of pearl millet cultivars inoculated with nitrogen-fixing bacteria, ICRISAT Center, rainy season 1984[1].

Culture	Grain yield (kg ha^{-1}) Cultivar BJ 104	WC-C75	ICMS 7703	BK 560	Mean
A.lipoferum (ICM 1001)	3390	3110	3380	2920	3200
A. chroococcum (ICM 2001)	3630	2990	3150	3130	3225
A. hrasilense (1)[2]	2770	3050	2920	2910	2910
A. hrasilense (2)[2]	2970	3070	3140	3220	3110
A. brasilense (1+2)[2]	3060	3250	3140	2680	3030
NBRE[3]	2930	2990	2880	2780	2890
Noninoculated control	2600	3350	2580	3040	2890
SE		±168			±86
Mean	3050	3120	3030	2960	
SE		±63			
CV (%)		13			

1. Mean of 6 replications. Net area harvested 6 m^2, a basal fertilizer dose of 20 kg N and 9 kg P ha^{-1} was applied. Each plot was inoculated once, 10 days after sowing, with 2.5 L of liquid inoculum prepared by suspending a 70-g peat culture (viable bacterial count of 10^8 cells g^{-1} of peat) in 70 L of water.
2. Cultures obtained from IARI, New Delhi.
3. Napier Bajra Root Extract.

Table 11. Grain yield (kg ha^{-1}) of pearl millet cultivars inoculated with nitrogen-fixing bacteria, Bhavanisagar, rainy season 1984[1].

Culture	Cultivar BJ 104	WC-C75	ICMS 7703	BK 560	Mean
A.lipoferum (ICM 1001)	1490	1890	1570	1650	1650
A. chroococcum (ICM 2001)	1420	1600	1270	1620	1480
A. brasilense (SL 33)[2]	1560	1720	1580	1640	1630
NBRE[3]	1220	1490	1220	1510	1360
Noninoculated control	1240	1430	1270	1610	1390
SE		±128			±61
Mean	1390	1630	1380	1610	
SE		±68			
CV (%)		16			

1. Mean of 4 replications. Net area harvested 6 m^2, a basal dose of 20 kg N and 9 kg P ha^{-1} was applied. Each plot was inoculated at sowing with 2.5 1. of liquid inoculum prepared by suspending a 70-g peat culture (viable bacterial count of 10^8 cells g^{-1} of peat) in 70 1, of water.
2. Culture obtained from the University of Alberta, Edmonton, Canada.
3. Napier Bajra Root Extract.

Screening Bacterial Strains

We screened twenty-four strains of nitrogen-fixing bacteria in association with plants of BJ 104 grown in glass tubes filled with nonsterilized Alfisol, on a sand:farmyard manure (FYM) mixture (97:3) media. We used the intact plant tube assay method (ICRISAT Annual Report 1982, p. 88) to assay the plants' nitrogenase activity three times during a 30-day growth period. This assay method is designed for screening bacterial strains for their ability to stimulate nitrogenase activity in association with pearl millet plants. Nitrogenase activity at 22 days in plants grown in sand:FYM medium, and inoculated with different strains of nitrogen-fixing bacteria varied from 31-132 nmol C_2H_4 $plant^{-1}$ h^{-1} compared to 10 nmol C_2H_4 $plant^{-1}$ h^{-1} for the noninoculated control. Similarly, the nitrogenase activity at 21 days in plants grown in nonsterilized Alfisol varied from 2-68 nmol C_2H_4 $plant^{-1}$ h^{-1} compared to 1 nmol C_2H_4 $plant^{-1}$ h^{-1} in the noninoculated control. Total plant dry matter varied from 113-168 mg $plant^{-1}$ in sand: FYM medium and 132-178 mg $plant^{-1}$ in soil with inoculation, compared to 100 and 138 mg $plant^{-1}$ for non-inoculated plants in the respective growth media.

Mycorrhiza

Utilization of Rock Phosphate

We aimed to increase the availability of phosphorus in rock phosphate, a cheaper but sparingly-soluble phosphorus fertilizer, using vesicular-arbuscular mycorrhiza (VAM). Phosphorus absorption by plants given acidulated Kodjari rock phosphate at 4 kg P ha^{-1} was increased nearly fourfold by VAM, compared to the control. Mycorrhizal benefits to pearl millet were higher with lower levels of rock phosphate than with the addition of higher levels,

Efficiency of phosphorus absorption from rock phosphate varied among VAM species and isolates. Ten VAM cultures were tested for their phosphorus-uptake efficiency from Kodjari rock phosphate. In comparison to the noninoculated control, the percentage increase in plant dry-matter response to VAM inoculation ranged from 11 *(Glomus epigaeum)* to 305 *(Glomus monosporum* 2) (Fig. 9). Phosphorus uptake from Kodjari rock was increased by 169% with *G. monosporum* inoculation but only by 16% with *G. epigaeum.* Within a species, the two isolates of *G. monosporum* (1 and 2) differed significantly in their effects on plant dry matter and phosphorus uptake, indicating a need to select efficient VAM isolates. These results indicate that inoculating with VAM when using rock phosphate as a fertilizer might be especially beneficial in the low phosphorus, sandy soils of the semi-arid tropics.

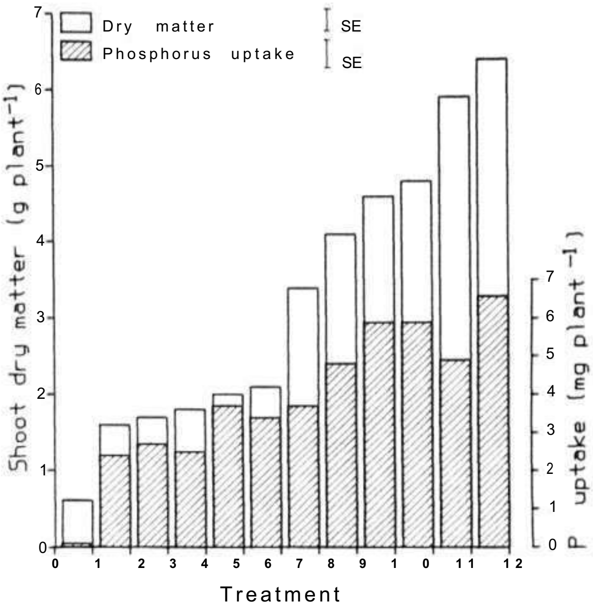


Figure 9. Response of pearl millet cultivar BJ 104 to inoculations with various mycorrhizal fungi in Alfisol amended with Kodjari rock phosphate (at the rate of 6 kg P ha^{-1} basal), ICRISAT Center, 1984. Treatments: 1 = Control, 2=Rock phosphate (RP), 3=RP + *Glomus epigaeum*, 4 = RP + *Gigaspora calospora,* 5 = RP + *Glomus monosporum,* 6= RP + *Glomus caledonium,* 7 = RP + *Glomus clarum,* 8=RP + *Glomus fasciculaturn,* 9=RP + *Gigaspora margarita,* 10 = RP + *Glomus mosseae,* 11 = RP + *A caulospora* sp, 12 = RP + *Glomus monosporum.*

Genotype-Dependent Colonization

We showed earlier (ICRISAT Annual Report 1983, p. 89) that the extent of root colonization by VAM, phosphorus uptake, and plant growth in pearl millet depend in part on the millet genotype. Genotype-dependent variation in mycorrhizal colonization was further confirmed by results obtained from field trials we conducted at ICRISAT Center and Bhavanisagar in 1984 (Table 12). For the 20 genotypes examined, the ranges in percentage colonization were 19-39 for ICRISAT Center and 21-46 for Bhavanisagar.

Table 12. Mycorrhizal colonization of 20 genotypes of pearl millet, ICRISAT Center and Bhavanisagar, rainy season 1984.

	VAM colonization (%)[1]		
Genotype	ICRISAT Center	Bhavanisagar	Mean
IP 4382	21	21	21
ICH 220	19	32	25
IP 3277	24	28	26
IP 6114	26	27	26
IP 5427	23	31	27
IP 4861	20	35	28
IP 3476	28	31	29
IP 4807	28	32	30
BJ 104	21	40	30
IP 5310	35	26	30
SDL	29	32	30
WC C75	28	35	31
MBH 110	31	32	31
IP 6538	29	38	33
IP 5140	32	35	33
IP 5009	32	36	34
Zanfarwa	33	40	36
IP 5921	32	42	37
IP 4937	39	40	39
IP 5150	33	46	39
SE	±8.3	±5.1	
Location mean	28	34	31
CV (%)		19	

1. Each value is a mean of 15 observations from three replicate plots each 4.5 m^2.

Extent of Plant-VAM Association

In Rajasthan, northwestern India, pearl millet roots and rhizosphere soil were sampled to estimate the extent of VAM colonization, propagule number (soil infectivity), and phosphorus status in the soil and plant (Table 13). Soil phosphorus available (Olsens' P) to the plant ranged from <0.5 ppm to 3 ppm across locations, indicating a low phosphorus status. Mean mycorrhizal colonization was 55-60%. VAM infectivity of soils in low rainfall districts was very low compared to that in intermediate rainfall regions, probably because VAM does not survive well in dry soils. Considering that plant growth and percentage shoot phosphorus were near normal (0.2% dry mass), it is possible that pearl millet derives considerable benefit from VAM association. This effect could possibly be further enhanced by selecting more efficient associations.

Nearly 70 VAM isolates from Rajasthan are now being cultured on *Cenchrus ciliaris* at ICRISAT Center, and they will be tested for their growth-stimulation efficiency. Some of the fungi sporulate profusely (Fig. 10 a and b) and are easy to multiply in large quantities. A culture producing two spore types, a large one with subtended attachment (Fig. 10 c) and a smaller one on a branching, thinner mycelium, with '*Glomus* type' attachment, was observed for the first time from the Rajasthan isolates.

Plant Improvement

Genetic Resources Utilization

We planted over 1000 accessions from the Genetic Resources Unit, identified by them as having 1000 grain mass of more than 9.0 g, and flowering in less from 80 days. The resultant gene pool will be very variable for many agronomic traits, and will be improved for large seed size using simple mass selection.

Two of the highest-yielding hybrids in the Pearl Millet Advanced Hybrid Trial (PMAHT) in 1984, ICMH 83506, and ICMH 83507, utilized pollinators bred in our Genetic Diversification Project (Source Material Project); one pollinator was derived from a cross between B 282 and S 10B, and the other from a cross between S lOBand LCSN 1225 (Table 14). Three additional hybrids from pollinators bred in the Genetic Diversification Project are under test in the AICMIP Initial Hybrids Trial, 1984.

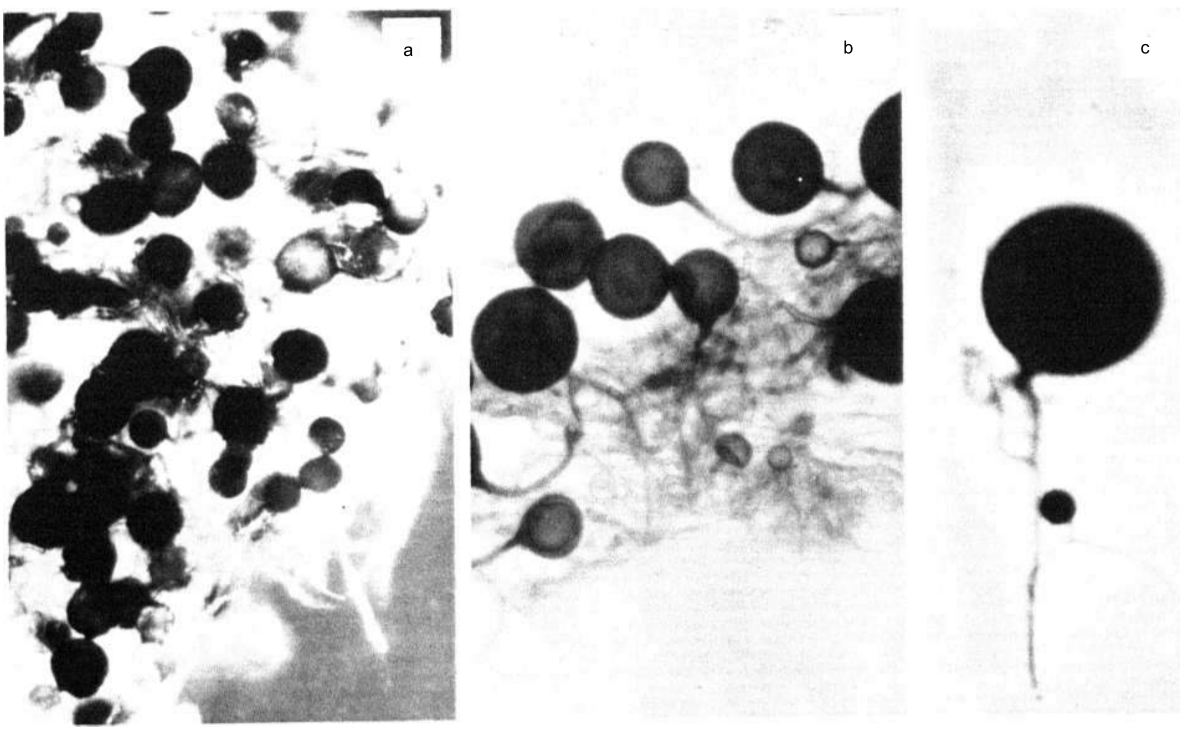
Two varieties (ICTP 8202 and ICTP 8203) bred by intermating selected S_2 progenies from material collected in Togo are performing well.

Table 13. Mycorrhizal status of roots, propagule density in rhizosphere, and shoot phosphorus concentration of pearl millet in farmers' fields, Rajasthan, India, rainy season 1983.

District[1]	VAM colonization (%)[2]	Soil infectivity (propagules/ 100 mL)[3]	Shoot phosphorus (% dry mass)
Low rainfall districts			
Bikaner	48 ± 2.5	65 ± 14.4	0.26 ± 0.050
Churu	49 ± 5.5	257 ± 44.8	0.23 ± 0.035
Nagaur	60 ± 3.6	104 ± 15.3	0.26 ±0.115
Jaipur (west)	51 ±9.5	2360 ± 0	0.15 ±0.031
Jodhpur	60 ± 3.7	1056 ± 281.1	0.15 ±0.014
Sikar	69 ± 3.1	2360 ± 0	0.31 ±0.040
Intermediate rainfall districts			
Alwar	54 ± 2.6	1435 ± 462.4	0.23 ± 0.033
Jaipur (east)	63 ± 3.7	2358 ± 0	0.17 ±0.022

1. Each value is a mean of 4-12 fields within each district; each field mean was derived from three random plants.
2. Low rainfall districts receive <350 mm and intermediate rainfall districts receive >500 mm rainfall during the rainy season.
3. Soil infectivity estimated by most probable-number method using soil dilution.

Figure 10. Mycorrhizal fungi isolated from sandy soils in Rajasthan, India, a. and b. profusely-sporulating *Glomus* species (x100); c. fungus with two spore types borne on the same mycellium (x200).



ICTP 8203 (Fig. 11) is in AICMIP trials and was the second ranked variety in the International Pearl Millet Adaptation Trial (IPMAT9) 1984, across 11 Indian locations (Table 20). ICTP 8202 is performing well in Sudan. The two top-ranked hybrids in IPMAT 9, (ICMH 505 and ICMH 82601) were also on pollinators bred in our Genetic Diversification Project (Table 20).

Figure 11. Heads of pearl millet variety ICTP 8203 bred by intermating selected S_2 progenies from germplasm accessions collected in Togo.

Hybrid Testing and Pollinator (R-line) Breeding

The top-yielding hybrids in PMAHT yielded 109% to 116% of the control hybrid MBH 110, and 126% to 133% of ICMS 7703, the control synthetic variety (Table 14).

Through recurrent selection for specific combining ability in a cross between ICP 165 and ICP 105 using male-sterile line 81A (ICMA l)as tester, we observed a yield superiority of the derived hybrids of more than 30% over ICMS 7703 (Table 15).

Sixteen advanced pollinators have been improved for DM resistance, a collection of 264 elite, restorer lines has been established for crossing on to new male steriles, and 20 elite pollinators have been random mated to establish the Restorer Composite II. Rapid generation advance (3 generations a year) in progenies of six composites is being followed to derive homozy-

Table 14. Performance of selected pearl millet hybrids for grain yield (kg ha^{-1}), days to 50% flowering, and plant height (cm) at ICRISAT Center, Bhavanisagar, and Jalna, and DM incidence at Bhavanisagar, Pearl Millet Advanced Hybrid Trial (PMAHT), rainy season 1984.

	Grain yield (kg ha^{-1})							
Entry	ICRISAT Center	Bhavanisagar	Jalna	Mean grain yield (kg ha^{-1})	Rank	Days to 50% flowering	Mean plant height (cm)	DM incidence (%)
ICMH 83506	4210	3670	3140	3670	1	52	195	0
ICMH 83507	4140	3390	3260	3600	3	53	200	0
ICMH 83401	4100	3230	3240	3520	5	52	200	0
ICMH 83402	4000	3030	3350	3460	8	52	210	0
Controls								
MBH 110	3620	2550	3300	3160	15	46	180	0
ICMS 7703	3290	2370	2590	2750	23	52	205	1
WC-C75	3080	2560	2920	2860	24	51	210	0
BK 560	3320	2220	2480	2670	22	49	180	5
SE	±252	±210	±172			±0.53	±6.1	±0.2
Mean[1]	3740	2900	2940	3190		52	197	0.32
CV (%)	12	14	6					

1. Of 25 entries.

Table 15. Performance of test crosses of pearl millet S_1 lines from the cross ICP 165 x ICP 105 selected for specific combining ability using 81A as tester, ICRISAT Center, rainy season 1984.

Entries	Grain yield (kg ha^{-1}) Mean	Range	Days to 50% flowering	Plant height (cm)
Top 10 entries	3110 ± 238	2930-3390	53	150
Whole trial (141 test entries)	2280±365	1470-3390	54	135
Controls[1]	1880		46	130

1. Means of three controls, ICMS 7703, WC-C75, BK 560.

gous, DM-resistant, inbred lines for test crossing on to new male-sterile lines.

At ISC, Niamey, 92 test crosses were made on three potential male-sterile lines and on 81A. Seven of the test-cross hybrids were found promising, and seed will be increased for evaluation in large plots in 1985. In general, the first experience of evaluating hybrids at ISC proved to be valuable. Hybrids were relatively early with reduced height, ear length, and increased tillering. However, DM pressure was not high enough to compare the reaction of testcrosses with susceptible controls; this will need to be monitored carefully in the future. The hybrids appeared to have a higher yield potential than local, or improved local varieties, but this needs to be confirmed using a range of male steriles and pollinators over the next few years.

Breeding Male-Sterile Lines

The dwarf male-sterile line 81A is now finding increasing use in the Indian hybrid programs. Two hybrids on 81A were among the highest-yielding hybrids identified in the PMAHT. Four more male-sterile lines, 833A, 843A (ICMA 2), 842A (ICMA 3), and 834A (ICMA 4), were found promising in AICMIP's male-sterile lines nursery, and have been recommended by AICMIP for general use as seed parents. Results of replicated trials of the hybrids made on these male-sterile lines indicate that estimates of their general combining ability varied from one test to another. In general, all these male-sterile lines were as good in hybrid combination as 81A. They can be expected to produce as high, or higher-yielding hybrids than 81A or 5141 A, that flower up to a week earlier in the growing season and have larger seed.

On the basis of results published by workers in the USA, we have started experiments on using the antibiotic Mitomycin to induce mutations for cytoplasmic male sterility in two maintainer lines, 834B (ICMB 2) and 833B, which have different cytoplasmic backgrounds.

The genetic base of the male-sterile program, in the A1 cytoplasm system, has undergone substantial diversification with the availability of 1266 F_4 progenies (397 derived from BxB and 849 from BxR crosses), and 354 F_5 progenies (779 from BxB and 75 from BxR crosses). These progenies have a wide range of maturity, head type, seed size, and tillering ability, and all of them are in the early- and medium-maturing groups.

At ISC, Niamey, male-sterile lines with eight different genetic backgrounds are now in the 3rd to 7th backcross generation. Several new inbreds have been identified for possible conversion into male-sterile lines.

Breeding Population Varieties

Seven pearl millet composite populations, which differ in maturity, plant height, and yielding ability are being improved by using S, and modified half-sib recurrent selection for grain yield, adaptation, and resistance to diseases. By the end of the 1984 summer season the following cycles of selection were completed in the composites: 7 in Medium and Super Serere, 5 in Early and Inter Varietal, 4 in New Elite, 3 in D_2 Dwarf, and 2 in the Smut Resistant Composite.

In each cycle, 50-60 superior progenies are recombined to reconstitute the population to start the next cycle of selection. From the families of S_1 lines which performed well, 15-20 superior progenies are identified, and on the basis of specific and across-location performance, are crossed in groups of 5-9 to form population varieties. After their test in ICRISAT initial, advanced, and international multilocational trials, the best performing varieties are entered in the AICMIP trials, conducted at nearly 20 locations in India. Five varieties from earlier cycles of composites, 2 from the New Elite, and 3 from the Inter Varietal composites are currently under test in these trials. Out of these, IVC-P78 showed the highest grain yield in its 2 years of AICMIP tests, i.e., the 1982 Pearl Millet Initial Population Trial (PMIPT) and the 1983 Pearl Millet Advanced Population Trial (PMAPT). NELC-H79 gave the highest grain yield in its first test in the initial AICMIP trial in 1983.

The gradual, cyclic improvement of the composites has led to the development of higher-yielding varieties from their advanced cycles. Of the 33 varieties formed in 1982, 16 out-yielded WC-C75 in the Pearl Millet Initial Variety Trial (PMIVT), 1982, and the Pearl Millet Advanced Variety Trial (PMAVT), 1983. Five of them with grain yields of 108 to 115% of WC-C75 were promoted to IPMAT 1984. ICMV 82132, a higher-yielding variety bred from the Smut Resistant Composite, showed good levels of resistance to both smut and DM and was the top-performing variety in IPMAT 1984 over 11 Indian locations (Table 20).

Of the 39 varieties tested in PMIVT in 1983,20 out-yielded WC-C75, and 8 of these showed a yield superiority of 110 to 116% in PMAVT in 1984 (Table 16). Medium, New Elite, and Inter Varietal Composites were the source of most of the higher-yielding varieties.

Twenty-five varieties were bred from the latest cycles of New Elite, Medium, and Smut Resistant Composites tested in PMIVT, 1984. Eight varieties from New Elite, 7 from Medium, and 10 from the Smut Resistant Composite showed a mean superiority for grain yield of 119%, 120%, and 112% respectively, compared to WC-C75 (Table 17).

Breeding Synthetic Varieties

Inbred lines and partial inbreds used as parents of synthetics are derived through pedigree selection from crosses between materials of various

Table 16. Performance of selected pearl millet varieties in Pearl Millet Initial Variety Trial (PMIVT) at five locations, and Pearl Millet Advanced Variety Trial (PMAVT) at three locations, rainy seasons 1983 and 1984.

		Grain yield (kg ha^{-1})						Days to 50% flowering[3]	
		PMIVT 83[1]			PMAVT 84[2]				
Entry	Composite source	Mean	Rank	% of WC-C75	Mean	Rank	% of WC-C75	PMIVT 83	PMAVT 84
ICMV 83117	Medium	2600	10	117	3000	1	116	52	50
ICMV 83101	Inter Varietal	2880	1	129	2970	3	115	55	54
ICMV 83131	New Elite	2590	11	117	2930	5	114	52	51
ICMV 83118	Medium	2780	5	125	2930	6	114	53	51
ICMV 83115	Medium	2410	26	109	2920	7	113	51	51
ICMV 83104	Inter Varietal	2870	2	129	2870	8	111	53	53
ICMV 83111	Medium	2360	29	106	2840	9	110	51	51
ICMV 83124	New Elite	2460	24	111	2840	9	110	52	52
Control									
WC-C75		2220	38		2580	30		50	50
SE		±296			±95			±0.5	±0.4

1. 39 test entries.
2. 28 test entries.
3. ICRISAT Center.

Table 17. Performance of selected pearl millet varieties in PMIVT. Means of Hisar, ICRISAT Center, and Bhavanisagar, rainy season 1984.

Varieties	Composite source	Grain yield ($kg\ ha^{-1}$) Mean	Rank	% of WC-C75	Days to 50% flowering
NELC-P8304	New Elite	3020	1	127	52
NELC-P8301	New Elite	2980	4	125	51
NELC-A83	New Elite	2970	5	125	51
All varieties (8)	New Elite	2840	-	119	51
MC-P8306	Medium	3020	2	127	49
MC-P8307	Medium	3020	3	127	51
MC-P8302	Medium	2960	6	124	49
All varieties (8)	Medium	2855	-	120	50
SRC-P8302	Smut Resistant	2890	8	121	51
SRC-H8301	Smut Resistant	2860	10	120	52
All varieties (10)	Smut Resistant	2660	-	112	51
Control					
WC-C75		2380	29	-	50
SE		±125			±0.6
Mean		2740			52

origins: parents of synthetics with proven performance, new lines from the genetic diversification project, population progenies, and agronomically-useful, disease-resistant lines. The inbred lines are identified as parents of synthetics on the basis of their performance and by an assessment of their combining abilities using a diallel crossing technique.

In 1984, we evaluated as potential parents 480 F_1s, 350 F_2s, 1500 to 2500 F_3 through F_6 progenies, and 425 inbreds. We tested 116 inbreds multilocationally in seven diallel combination groups, 53 synthetics in two initial trials, and 22 synthetics in one advanced trial.

Among the synthetics tested during 1984 in the Pearl Millet Advanced Synthetics Trial (PMAST), ICMS 8253, ICMS 8139, and ICMS 8274 were the top performers.

The Smut Resistant Synthetic, ICMS 8283, which performed well in previous years' tests, yielded 100% of the mean of the controls in IPMAT and was ranked 14.

Synthetics bred in this project and contributed to AICMIP trials, continued to be high-yielding. ICMS 7703 after 6 years of testing at 27 locations was recommended for all India release in April 1984 (Table 18). ICMS 7704, a top-performing entry across 27 locations in India since 1980, was entered in the 1984 national minikit trials.

The ISC pearl millet breeding program is in its 3rd year of operation. Efforts in variety breeding were devoted towards forming new populations, to evaluating new variability received from other programs in the region, generation of new variability, and to the evaluation of progenies derived from intervarietal crosses. During 1984 we were able to identify several progenies, based on performance data over the last 3 years, for use as synthetic parents.

Over 900 lines have been evaluated from other programs (ICRISAT/Institute for Agricultural Research (IAR), Nigeria, ICRISAT/Institut National de Recherche Agronomique du Niger (INRAN), and ICRISAT/Institut Senegalais de Recherche Agricole (ISRA). Thirty F_1 populations, 172 F_2 populations, and 1362 F_3, 235 F_4,

Table 18. Performance of selected pearl millet synthetics in Pearl Millet Advanced Synthetic Trial (PMAST) at four locations, rainy season 1984.

	Grain yield (kg ha^{-1})						%	Days	Plant	DM
			ICRISAT Center		Bhavani-		over	to 50%	height	incidence
Entry	Mean	Rank	HF[1]	LF[1]	sagar	Hisar	controls	flowering[3]	(cm)[3]	(%)[4]
ICMS 8253	2350	1	3120	730	2790	2740	121	52	232	2.8
ICMS 8139	2160	2	2760	620	2390	2850	111	51	226	4.4
ICMS 8274	2140	3	2460	760	2370	2990	110	51	224	2.4
ICMS 8240	2120	4	2850	560	2590	2500	109	51	225	3.0
ICMS 8261	2120	5	2520	610	2840	2500	109	50	220	10.6
ICMS 8102	2090	6	2690	590	2730	2360	108	50	220	4.1
ICMS 8148	2090	7	2400	560	2300	3090	108	52	216	4.2
ICMS 8152	2080	8	2390	650	2930	2350	107	51	219	4.8
Controls										
BK 560	2020	11	2730	620	2040	2700	104	47	205	1.4
VVC-C75	1940	19	2440	390	2650	2290	100	51	228	4.9
ICMS 7703[2]	1860	22	2550	520	1960	2400	96	49	222	6.6
SE			±159	±72	±252	±216		±0.4	±3.4	
Mean	2020		2560	580	2490	2450		50	218	
CV (%)			11	22	17	15		1.5	2.7	

1. HF=High Fertility, 80 kg N and 18 kg P ha^{-1}; LF=Low Fertility, 20 kg N and 9 kg P ha'.
2. Recommended for release in April 1984.
3. ICRISAT Center High Fertility.
4. ICRISAT Center Disease Nursery.

and 59 F_5 progenies were evaluated from crosses made at ISC. Various backcross and S, progenies have been evaluated and selections have been made to form synthetics.

Selection for Increased Grain Size

In a number of studies, we have found that grain number and grain size are not negatively correlated in pearl millet, as they are in most other cereals (ICRISAT Annual Report 1978/79, pp.68-69). This finding suggested that it might be possible to select for improved grain size without a corresponding decrease in grain number, and thereby to increase grain yield.

We initiated a study to test this hypothesis, using two open-pollinated varieties, ICMS 7703 and ICMS 7938. We grew approximately 1400 spaced plants of each on which the main head was left to cross-pollinate under natural conditions and the first tiller selfed to produce an S, progeny. Seed size was estimated on the main head as 100 grain mass. In 1984, a selection of S, lines representing a range of seed sizes in the S_0 plants were grown, to compare seed size in both generations and to estimate heritability of this trait. We also used data from this experiment to test the relationship of seed size to other yield components.

There was a broad range of individual seed sizes in the S_0 generation of populations; 0.50 to 1.40 g/100 seeds in ICMS 7703 and 0.35 to 1.35 g/100 seeds in ICMS 7938. Seed-size data from the S, progeny trial suggested that selection for seed size should be effective on ICMS 7703 where there was a correlation (r=0.50**) between S_0 plant and S, progeny row seed-size (Fig. 12). With ICMS 7938 the correlation coefficient was r=0.26.

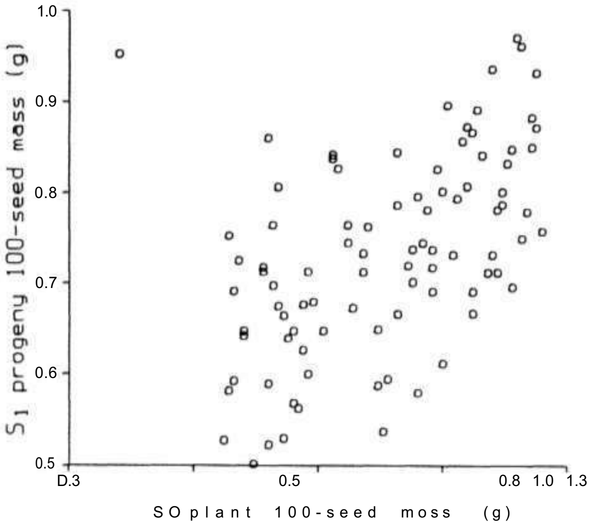


Figure 12. Relationship of ICMS 7703 S_1 progeny row mean seed size to S_0 plant main head seed size. ICRISAT Center, rainy season 1984.

We compared the effects of variation in grain size on yield and yield components for both populations (Table 19). Seed size was negatively correlated to grain number nr^2 as a consequence of a negative relationship to grain number panicle^{-1}. This was not totally unexpected, although it contrasts with previous comparisons among different cultivars, probably because differences in grain size were a result of specific selection rather than chance variation. Seed size was significantly related to grain yield panicle^{-1}, and as a consequence, to grain yield per unit area, only in ICMS 7703. Seed size, however, explained a lesser fraction of the variation in yield (19%) than did grain number (35%).

Table 19. Correlations of S, grain size to S, grain yield and yield components in pearl millet varieties ICMS 7703 and ICMS 7938, ICRISAT Center, rainy season 1984.

	ICMS 7703	ICMS 7938
Correlation of grain size and:	Correlation	coefficient
Panicles m^{-2}	-0.05	-0.12
Grain number panicle^{-1}	-0.33**	-0.26
Grain mass panicle^{-1}	0.33**	0.28
Grains m^{-2}	-0.46**	-0.37**
Grain mass m^{-2}	0.44**	0.26
Range in seed size (g/100 seeds)	0.50-0.97	0.42-0.87
Number of S, progenies	90	43

Individual S_1 progeny from ICMS 7703 which combine a large seed size (at least one SE greater than the mean of the original population) and good grain yield (equal to that of the original population) will be recombined to form a new synthetic to test the effect of selection for larger seed size on grain yield.

International Cooperation

As in previous years, the major activities of this project were distributing elite breeding material to cooperators through trials and nurseries, participation in the National coordinated trials in India and meeting the seed requests of cooperators. The IPMAT 9 had 20 entries (8 hybrids, 5 synthetics, and 7 varieties). The trial was dispatched to 30 locations in India, Pakistan, and Niger. The results from 11 locations in India indicated that ICMH 505 and ICMH 82601 were the highest-yielding hybrids. The highest-yielding varieties were ICMV 82132 (a smut-resistant, population variety), ICTP 8203 (also in AICMIP trials), ICMV 82113, ICTP 8202, and ICMS 8283 (a smut-resistant, synthetic variety) (Table 20). It is very encouraging that ICMH 505 is a semi-dwarf hybrid, the result of a cross between a new d_2 dwarf male-sterile (843 A) and a d_2 dwarf pollinator, and that two of the best-performing varieties are resistant to both DM and smut.

Thirteen varieties, hybrids, and synthetics from ICRISAT were included in various AICMIP trials in 1983, with WC-C75 (ICMV 1) as one of the standard controls. The performance of ICRISAT varieties continues to be superior when compared to other entries, including controls (Table 21).

Our regular trials, and in particular our nurseries, have continued to be a valuable source of genetic material for cooperators' breeding programs. The ICRISAT Pearl Millet Uniform Progeny Nursery was requested by more than 20

Table 20. Mean performance of selected entries in the International Pearl Millet Adaptation Trial (IPMAT 9), across eleven locations in India, 1984.

Entry	Grain yield (kg ha^{-1})	Rank	Days to flowering	DM (%)	Smut (%)[1]
ICMH 505	2120	1	53	18.3	-
ICMH 82601	2120	2	52	0.9	-
ICH 433	1900	5	55	5.5	-
ICMV 82132	1870	8	55	1.7	4
ICTP 8203	1810	10	51	3.2	-
ICMV 82113	1770	11	54	3.1	-
ICTP 8202	1770	12	51	0.6	-
ICMS 8283	1760	14	54	1.7	<1
Controls					
MBH 110	2110	3	50	4.5	
ICMS 7703	1720	17	53	5.8	
WC-C75	1640	22	52	3.3	
Local	1570	24	52	1.9	52[2]
SE	±53		±0.3		
Mean	1810		53		

1. Mean of four locations in International Pearl Millet Smut Nursery (IPMSN), 1984.
2. BJ 104.

cooperators in India and the Inbred Nursery is increasingly attracting the attention of co-operators.

We continued to supply on request seed of pearl millet lines and populations to other pearl millet programs. In 1984, seed of our 2500 selections were dispatched to pearl millet scientists in India and several countries in Africa. These included many specific entries requested from our breeding and pathology nurseries which were shown during the Scientists' Day and at other times during the year.

During the year, the annual ICRISAT Pearl millet African Zone-A Trial (IMZAT) for drier zones was conducted across the West African millet zone principally to evaluate the elite products of the ICRISAT Cooperative Program in West Africa. IMZAT 84 contained 13 entries contributed by ICRISAT Cooperative programs in Burkina Faso (2 entries), Niger (4), Nigeria (4), and Senegal (3). An improved variety and a farmers' traditional variety were included as controls at each of the locations. The trial also contained Souna III, a released variety from Senegal, used as a long-term control. This trial was sent for yield evaluation to 13 locations in 9 countries (including one location each in Botswana, Zambia, and Zimbabwe, sown in October 1984). The trial was also sent for evaluation in the *Striga* nursery (Kamboins6, Burkina Faso), and for pest and disease incidence at ISC.

To date we have received data from 7 locations in 4 countries (Cameroon, Mali, Niger, and Senegal); grain-yields from these locations are given in Table 22.

In 1984, the rainfall at almost all locations was well below normal. Highest mean yield was recorded at Cinzana, Mali (1950 kg ha^{-1}) and lowest at Maroua, Cameroon (528 kg ha^{-1}). At all locations the 'unimproved farmers' local' was the lowest-yielding entry. Over all locations, entries ITMV 8304, INMV 8220, and IBMV 8301 did well relative to the mean yield of the trial (1227 kg ha^{-1} over 7 locations).

Senegal

Breeding

Our objectives are to improve grain yield and its stability, grain size, harvest index, resistance to diseases and pests, productive-tillering ability, and to determine the best cultural practices for newly-bred varieties. We continued to generate new breeding material including synthetics and hybrid varieties suitable for different agroclimatological zones of Senegal.

Plant Improvement

Inbreds and synthetics. One hundred and two F_6 progenies generated from 1977 to 1983, from crosses between improved Senegalese material and Indian introductions, 99 F_5, and 200 F_4 progenies derived from Senegalese x non-Senegalese crosses during 1981 to 1983 were evaluated this rainy season for their performance at Nioro and Bambey. These 401 inbreds/partial inbreds are being cataloged for their use-

Table 21. Yield performance of ICRISAT pearl millet entries in All India Coordinated Millet Improvement Project (AICMIP) trials, 1983.

			ICRISAT entries				Trial mean yield	Top-yielding	
	No. of locations	No. of entries	Entry	Years in test	Grain yield (kg ha^{-1})	Rank	(kg ha^{-1})	Entry	Grain yield (kg ha^{-1})
Initial Pearl Millet Hybrid Trial 1	19	24	ICH 415	1	1940	6	1760	MBH 138	2090
			ICH 423	1	2050	3			
Advanced Pearl Millet Hybrid Trial 11	32	20	ICH 440	2	2170	6	205	MBH 131	2340
Initial Pearl Millet Population Trial IV	18	26	ICMS 8021	1	1560	3	127	NELC-H79	1630
			NELC-H79	1	1630	1			
Control			WC-C75		1510	5			
Advanced Pearl Millet Population Trial V	30	18	ICMS 7703	6	1750	5	169	IVS-P78	1810
			IVS 5454	4	1750	6			
			ICMS 7704	4	1800	2			
			ICMS 7818	3	1740	7			
			ICMS 7835	3	1790	3			
			NELC P79	3	1740	8			
			IVS-P78	2	1810	1			
			DIC P7904	2	1660	15			
Control			WC-C75		1770	4			

ful characteristics. During the off-season 1983/84, selected progenies were utilized to form 18 synthetics and 131 testcrosses. Four new synthetics suitable for different agroclimatological regions of Senegal are being generated from 40 selected inbreds during the off-season, 1984/1985.

Hybrids. Twenty-two selected hybrids tested in 1983 were retested in 1984 at both Nioro and Bambey. The highest-yielding hybrid was ICMH 8407 SN which yielded 61% (2575 kg ha^{-1}) more than Souna III, followed by 8413, 8403, and 8411. Five hybrids, ICMH 8403, 8404, 8412, 8413, and 8414, gave significantly higher grain yields than Souna III in both 1983 and 1984. These seven hybrids will be retested in 1985, as will 13 of 109 newly generated testcrosses involving different male-sterile lines and new inbreds. Fifteen seed parents including 81 A, 111A, and J 1623 were moderately to highly susceptible to DM (14.3 to 80.0%) at Nioro. Efforts will be made to breed new seed parents with African backgrounds and resistance to diseases.

Improvement of synthetics. The first cycle of recurrent selection in Souna III and IBV 8004 (ICMV 3) was completed in the 1982 off-season. Shibras were eliminated from Souna III, but there was no improvement in its resistance to DM. The second cycle of recurrent selection in these synthetics using the half-sib method was completed in the 1983/84 off-season. The most important selection criteria were resistance to DM in Souna III, and grain yield in IBV 8004. In 2 years, DM incidence in Souna III was reduced from 24 to 14%, but grain yield was improved by only 3%. IBV 8004 was improved by 9% for grain yield. We started the 3rd cycle of recurrent selection in these varieties during the 1983/84 off-season by producing 432 half-sibs from each. Based on multilocational testing, 38 progenies from each of the two synthetics were selected for

Table 22. Grain yields (kg ha^{-1}) of five best entries and the local and improved controls in ICRISAT Pearl Millet African Zone A Trial (IMZAT), seven locations, rainy season 1984.

	Bambey, Senegal		Cinzana, Mali		ISC, Niger		Koporo Keniepe, Mali		Maradi, Niger		Maroua, Cameroun		Nioro, Senegal	
Rank	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield
Top	INMV 8220	1300	IBMV 8401	2280	ITMV 8303	1350	M2D2	1360	ITMV 8304	1310	IKMV 8201	1140	INMV 8210	2460
Second	IBMV 8001	1280	IBMV 8302	2250	ITMV 8301	1250	Souna III	1290	ITMV 8303	1040	IBMV 8301	1072	INMV 8220	2280
Third	IBMV 8302	1180	Souna III	2160	ITMV 8304	1240	ITMV 8301	1260	INMV 8220	1030	ITMV 8304	773	INMV 8240	2180
Fourth	INMV 8240	1140	INMV 8240	2130	INMV 8240	1200	ITMV 8304	1230	IKMV 8101	990	INMV 8212	740	IKMV 8101	2180
Fifth	IBMV 8301	1140	Boboni	2090	INMV 8220	1170	IBMV 8301	1150	IBMV 8301	980	ITMV 8303	718	INMV 8212	2150
Control														
Local	Bambey	610	Boboni	2090	Haini-Kirei	630	NBB	820	Maradi	550	Mouri	0	Bambey	720
Improved	IBMV 8001	1280	Syo-5-1	1690	CIVT	1120	M2D2	1360	CIVT	710	Souna III	572	IBMV 8001	1940
SE		±128		±140		±92		±142		±120		±137		±200
Location mean		1040		1950		1090		1010		860		528		1890
CV (%)		30		18		21		31		34		55		26

recombination. The selected half-sib families are being recombined using S_1 seed from DM-free plants. The final comparisons between the reselected and the original synthetics will be made in 1985.

Improvement for grain mass by backcrossing in IBMV 8401 (ICMV 2), a dwarf variety, was initiated in 1984 by crossing it with two high seed mass lines from Ghana, IP 16151 and IP 16152. The F_1 crosses were grown for generation advance in the 1984 rainy season. F_2 populations are being grown during the 1984/85 off-season and the dwarf plants will be backcrossed to IBMV 8401.

Trials and Nurseries

Advanced yield trial. During 1984, all the entries in the Advanced Yield Trial, except IBMV 8401, were significantly superior in grain yield to Souna III, and the local control, which suffered from a severe drought at flowering and grain filling. During 5 years of testing, IBV 8001 averaged 24%, and IBV 8004 21% higher yields than Souna 111; both entries had greater resistance to DM, a higher 1000-grain mass, and matured 7 to 10 days earlier than Souna III. In 1984, these two varieties were grown on more than 1000 ha by farmers, and the national seed service multiplied seed. Village women told us that these varieties produced more and better-tasting *couscous* than their local millet. These two varieties along with H7-66 and IBMV 8401 were recommended by ISRA for release in Senegal. H7-66, bred by the national program, yielded 18% more than Souna III in 4 years of testing. IBMV 8401 had a grain yield equivalent to Souna III over 3 years of testing. The national seed service multiplied it on 13 ha and harvested 13 000 kg of good quality seed (Fig. 13). The seed growers appreciated this variety because of its high tillering, earliness, and good fodder quality due to its resistance to diseases and lodging, and the ease of farm operations made possible by its short stature.

Synthetics trial. Eighteen synthetics were evaluated during the 1984 rainy season at Nioro and

Figure 13. ICRISAT pearl millet scientist discussing seed multiplication with ISRA millet breeder. National Seed Service staff, and local seed producers, Senegal, 1984.

Bambey, based on their yields in the 1983/84 off-seasons. The highest-yielding synthetic was 1BMV 8406, with 10% more grain than Souna III. Nine synthetics were retained for additional testing in 1985.

Regional trials. Two synthetics, IBMV 8301 and IBMV 8302, were contributed to IMZAT, and 5 new synthetics and 25 inbreds were contributed to the ICRISAT exchange nursery. Based on results of this trial from Nioro and Bambey, material bred in Nigeria and Niger is seemingly adapted to Senegalese conditions. The highest-yielding entries were INMV 8210 (1796 kg ha^{-1}), INMV 8220, and INMV 8240. Nine entries produced similar grain yields to INMV 8210. Souna III, and the local farmers' variety were the lowest-yielding entries in the trial.

Among varieties in the exchange nursery, the highest-yielding were IBMV 8406 (top-yielder in the synthetics trial), followed by ITMV 8303, IBMV 8405, and IBMV 8402. The top eight inbreds were from Senegal; four were selected because of their high grain yield and disease resistance. One of the inbreds, ICMI 84015 SN, gave grain yield equivalent to Souna III.

Development of Cultural Practices

A trial consisting of four varieties, Souna III, H7-66, IBV 8004, and IBV 8401, at two spacings (90*90 cm and 90 x 45 cm) with two plants $hill^{-1}$, and three treatments (no fertilizer, N31 : P21 : K21, and N61 : P31 : K31) was planted at Bambey during the 1984 rainy season. Due to drought, the increased plant population (90*45 cm) reduced grain yield by 25%. We could find no significant effect of increasing fertilizer on grain yield. The highest-yielding entry was IBV 8004 followed by H7-66, IBMV 8401, and Souna III. From 3 years' results, we can conclude that increased plant population does not significantly increase grain yield or economic returns. Therefore, a 90x90 cm spacing is recommended for both tall and dwarf varieties in Senegal.

Burkina Faso

Like many African countries, Burkina Faso experienced drought in 1984, the severity of which varied between and within regions. Rainfall during the 1984 crop season was less than 50% of the long-term average at Kamboinse and Ouahigouya, the two major millet trial locations.

The main objective of the program is to breed two groups of varieties for the 500- to 900-mm rainfall zone. The growth characteristics of these two groups are:

1. Photoperiod-sensitive full-season (120-150 days to maturity) varieties that farmers can sow with the late May/early June rain,
2. Photoperiod low-sensitive/insensitive, early-maturing (80-110 days) varieties for late (July) or very early (May) sowing.

Plant Improvement

The major thrust of our research activities is on breeding full-season (120-150 days), photoperiod-sensitive varieties. Research experience and observations of farmers' practices and crop performance have clearly indicated that the photoperiod sensitivity of local cultivars allows flexibility in time of sowing. Since flowering always occurs towards the end of the rainy season, such genotypes are more likely to escape pollen wash, and insects that eat floral parts and feed on immature grain. However, photoperiod-sensitive varieties have the disadvantage of being restricted to rather narrow north/south zones of adaptation.

The breeding of photoperiod-sensitive, late-maturing varieties is hampered by several factors including drought, which generally delays flowering, and the apparent superior vigor of early genotypes over photoperiod-sensitive, late ones in the seedling stage. However, in some crosses it seems that the hairy-leaf character, which can be detected in seedlings, segregates with photoperiod sensitivity, and as such it might be a useful tool for identifying photoperiod-sensitive plants at the seedling stage in a segregating population. We initiated a test to confirm these observations in an F_2 population from a promising cross of Kapelga (photoperiod-sensitive, late) x GT 79 (less photoperiod-sensitive, early). Progeny from this cross (and some related material) were densely sown in an off-season nursery, seedlings were then screened for the hairy-leaf character, transplanted, and the resulting plants selfed. A progeny test for flowering behavior and agronomic performance was planned for the 1984 rainy season, but it could not be pursued because of early-season drought (irrigation was not possible). Early sowing (by mid-June) is necessary for this evaluation of photosensitivity so that there is an adequate spread of flowering to enable selection for maturity and photoperiod sensitivity differences.

In an effort to breed early-maturing, bristled varieties, seed was selected from open-pollinated, bristled heads which sporadically occur in variety IKMV 8101 and the local cultivar, CVP 210. The IKMV 8101-derived lines showed monogenic segregation for the dominant bristle character, whereas CVP 210-derived lines did not show a clear cut segregation pattern. In general, seed set was poor on selfed, bristled heads compared to selfed, non-bristled heads. However, some bristled, homozygous lines were derived from IKMV 8101 which had relatively better seed set. These are now being recombined.

Trials and Nurseries

Early-maturing varieties for late sowing. We continued multilocational trials to identify early-maturing varieties for late-sowing conditions. The superior performance of the varieties IKMV 8101 and IKMV 8201 reported earlier

Table 23. Performance of selected early-maturing experimental pearl millet varieties in Burkina Faso, rainy season 1984.

	Aourema		Ouahigouya	
	Grain yield (kg ha^{-1})	Days to 50% flowering	Grain yield (kg ha^{-1})	Days to 50% flowering
IKMV 8201	450	69	370	65
IKMV 8101	400	68	290	74
IKMV 8301	400	75	360	72
IKMC 1	320	81	300	76
Local control	200	81	180	82
SE	±50		±50	
CV (%)	40		50	

(ICRISAT Annual Report 1983, p. 106) was repeated during the 1984 season at Aourema and Ouahigouya (Table 23). We could not analyze grain-yield data from Kamboinse because of severe drought. However, early-maturing varieties did produce some grain, but a late-flowering local control did not.

Full-season varieties. In 1984 we conducted two multilocational trials to further evaluate the performance and adaptation of full-season varieties in the 650- to 850-mm rainfall zone. The distance between the two farthest (north-south) locations was about 175 km. One multilocational trial, IMMLT 2, grown at Saria, Kamboinse, and Gampella (average annual rainfall approx. 800 mm), and at Ouahigouya (650 mm rainfall) had mostly entries of 130- to 150-day maturity. The other trial, IMMLT3, with entries of 120- to 130-day maturity, was conducted at Ouahigouya and Aourema, situated about 20 km apart. Material of this maturity is not adapted for normal sowing in the 800-mm rainfall zone.

The IMMLT 2 trial suffered extreme drought at Kamboinse and Ouahigouya but was less affected at Saria and Gampella. At these two locations the selections for low susceptibility to DM, CVP 480 and CVP 417, consistently outyielded the control cultivar, Kapelga. Average grain yields over these two locations were 875 kg ha^{-1} for CVP 480, 800 kg ha^{-1} for CVP 417, and 600 kg ha^{-1} for Kapelga. Compared to Kapelga, the cultivar commonly grown in the central Sudanian Zone, CVP 480 and CVP 417 have relatively long (39 vs 27 cm) and thick heads.

The IMMLT 3 trial results at Ouahigouya and Aourema confirmed the superior performance of the 82/83 Recombined Population Early (RPE) seen in 1983. Overall average grain yields at those locations for 82/83 RPE was 265 kg ha^{-1} and 145 kg ha^{-1} for the local control cultivar. In addition, one cultivar, CVP 170, with low susceptibility to downy mildew, exceeded the yield of the local control by 300% (430 vs 145 kg ha^{-1}).

Striga Resistance

The project on improvement of pearl millet for resistance to *Striga hermonthica* in Burkina Faso started in 1979 with financial assistance from the International Development Research Centre (IDRC). Since 1982, we have been doing pot experiments to test individual millet plants to complement our progeny testing in heavily-infested fields in Burkina Faso and Niger. The 1984 results of both field and pot screening were very encouraging. Some progenies selected from a less-susceptible base population exhibited high levels of resistance.

Field screening. Several F_7 and S_2 progenies gave very promising results in the International Pearl Millet Observation Nursery (IPMON) conducted in 1984 in Aourema village. Four entries, P 2627-2-11-2, P 449-1-29-4, Inbred 5258-1-19-1, and P 2627-2-18 had only 10% of the *Striga* plants appearing in adjacent susceptible plots of Ex-Bornu in a checkerboard design. Among 18 F_7 progenies tested, one, 82W634 (cross between a Burkina Faso variety and P 508), was outstanding with only 3% as many emerged *Striga* plants as appeared in adjacent plots of Ex-Bornu. Although yields of many resistance sources are poor, 82W634 yielded more than Ex-Bornu (640 vs 580 kg ha^{-1}). Out of 23 S_2 progenies, two showed reduced susceptibility and yielded more than Ex-Bornu. We will recombine 20% of the less-susceptible lines to start the second cycle of S_2 testing.

Screening in pots. Screening of individual millet plants in pots infested with *Striga* enables us to identify millet progenies with high levels of resistance. Highly-resistant selections supported fewer emerged *Striga* plants and survived, compared to susceptible ones which were heavily attacked and killed (Table 24). The selections from inbred 5258, P 449, P 2627, and Serere 2A-9 are the most promising. Some of the selections from inbred 5258, P 449, and P 2627 also performed well in field tests.

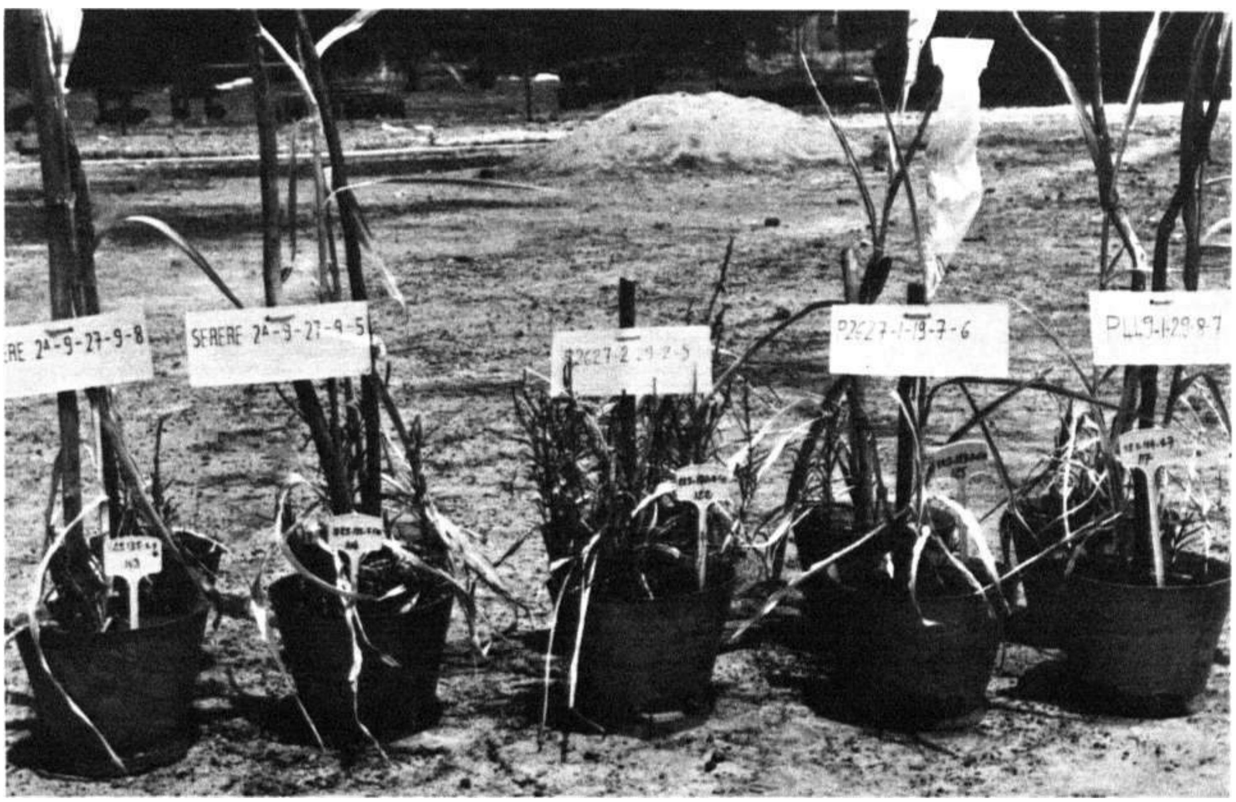
Niger

The 1984 pearl millet cropping season was beset by drought in all the locations we operated, with total rainfall only 30-50% of that expected. However, these conditions provided an oppor-

Table 24. Resistance to *Striga hermonthica* in selected progenies of pearl millet grown in *Striga*-infested pots, Kamboinse, Burkina Faso, summer 1984.

Progeny	Mean *Striga* plants pot^{-1}	Survival (%)[2]
Inbred 5258-1-19-4-5	0 (0.04)[1]	100
P449-1-29-8-7	2 (0.41)	100
Inbred 5258-1-19-4-2	2 (0.49)	100
P449-1-29-8-5	2 (0.47)	100
Inbred 5258-1-19-4-9	4 (0.66)	100
P2627-1-19-7-6	4 (0.66)	100
Serere 2A-9-27-9-5	4 (0.67)	100
Serere 2A-9-27-9-8	5 (0.73)	100
P2627-2-29-2-5 (susceptible)	25 (1.38)	0
P2627-1-29-1-4 (susceptible)	31 (1.50)	0
SE	±(0.111)	

1. Figures in parentheses are the mean number of *Striga* plants transformed using log (x+1.1).
2. Number of millet plants surviving to maturity as percentage of total plants counted at 40 days after sowing.



Four pearl millet progenies with resistance to *Striga hermonthica* growing in infected soil compared to a susceptible control (center), Kamboinse, Burkina Faso, summer 1984.

tunity to test the performance of our varieties under low rainfall conditions.

Trials and Nurseries

Three ICRISAT varieties, ITMV 8001, ITMV 8002, and ITMV 8304, bred in cooperation with INRAN research station at Maradi, have been recommended for release to farmers in Niger in 1985, based on their performance in multilocational trials. ITMV 8001 and ITMV 8003 have been recommended for farmers' field trials or demonstrations in millet-growing countries of the Sahel in 1985, because of their performance in 3 years of multilocational trials coordinated by the Institut du Sahel.

In the 1984 IMZAT, the ICRISAT/Niger bred variety ITMV 8304 was the highest yielder (1278 kg ha^{-1}) of all entries for the two Niger locations, Maradi and Sadore, and it was significantly (33%) higher than the control, CIVT, a variety released earlier by INRAN for general cultivation in Niger (Table 25).

Plant Improvement

In order to maintain desirable variability while avoiding inbreeding, we have formed four gene

Table 25. Performance of entries in IMZAT, Niger, 1984. Means of Maradi and Sadore (ISC) locations, average rainfall for the two locations 249 mm.

Entry	Source	Days to 50% flowering	Plant height (cm)	Earhead length (cm)	Grain yield (kg ha-')	% of CIVT
ITMV 8304	ICRISAT/INRAN[1]	68	200	36	1280	133
ITMV 8303	ICRISAT/INRAN	65	220	56	1210	126
ITMV 8301	ICRISAT/INRAN	67	220	55	1120	116
INMV 8220	ICRISAT/ABU[2]	64	190	35	1100	114
INMV 8240	ICRISAT/ABU	66	210	40	1080	112
ITMV 8305	ICRISAT/INRAN	66	200	39	1020	106
IKMV 8201	ICRISAT/IBRAZ[3]	66	190	29	1020	106
IBMV 8301	ICRISAT/ISRA	69	180	40	1000	104
INMV 8210	ICRISAT/ABU	66	200	36	980	104
IKMV 8101	ICRISAT/IBRAZ	67	220	40	990	103
IBMV 8401	ICRISAT/ISRA[4]	70	170	55	920	95
INMV 8212	ICRISAT/ABU	67	210	39	880	89
IBMV 8302	ICRISAT/ISRA	72	200	57	770	80
Controls						
CIVT	INRAN	69	230	58	960	100
Souna III	ISRA	74	200	57	730	76
Local-Zanfarwa (Maradi)		71	210	60	550	57
Local-Zongo (Sadore)		85	250	70	630	65
SE		±1.1	±7.7	±2.7	±106	
Mean		69	205	46	980	
CV (%)		4	8	14	27	

1. INRAN = Institut National de la Recherche Agronomique du Niger.
2. ABU = Ahmadu Bello University.
3. IBRAZ = Institut Burkinabe de la Recherche Agronomique et Zootechnique.
4. ISRA - Institut Senegalais de Recherches Agricoles.

pools: African gero (INMG1), Indiand_1 (INMG 2), d_2 derivatives, (INMG 3), and bristled head (INMG 4). This project was initiated by the ICRISAT/Niger Cooperative Program in 1979; a 5th gene pool, INMG 5 (thick-headed) was started in 1981. This project was successfully completed in 1984. The gene pools were formed by grouping together genotypes possessing similar head length and maturity, originating from similar agroclimatic zones in African countries and India, and allowing random mating. Seed of these gene pools and varieties derived from them has been made available to pearl millet breeders in Africa for evaluation and for them to use to derive varieties for their respective areas. Varieties derived from these gene pools by gridded mass selection in the advanced random mating cycles, have shown good performance in various national and regional trials. The performance of varieties ITMV 8001 and ITMV 8002 derived from INMG 1, ITMV 8003 from INMG 2, ITMV 8303 and ITMV 8004 from INMG 3, and ITMV 8304 from INMG 5 is being further improved by recurrent selection with S_1 testing at Maradi and the ISC, Sadore. The most promising S_2s are being recombined to reconstitute the respective varieties.

In order to combine desirable characters of popular pearl millet landraces from Niger, genotypes from other African countries and India, and other exotic accessions, a large number of crosses and backcrosses have been made. Many desirable segregants have resulted, and over 600 lines at the F_3 to F_8 generations have been selected. These lines are being used in testcrosses with the male-sterile line, 81A, to examine their potential as pollinators. From 59 selected inbreds (F_7), 11 synthetics were developed during the 1984 summer season, and they were tested in yield trials at Maradi and Sadore in the 1984 rainy season. Several of these synthetics outyielded CIVT. The inbred lines involved in making these synthetics were also test crossed on 81A, and evaluated at Maradi and Sadore. These lines will be retested in 1985.

During 1984, an attempt was made to standardize the biochemical procedure for isolating mitochondrial DNA (mt DNA) from pearl millet, in collaboration with the Biochemistry Department of Kansas State University, USA. This was to develop a method for easy identification and classification of different types of cytoplasmic male sterility in pearl millet, similar to that used for maize and sorghum. Although the study is still incomplete, preliminary results on quantitative estimation and electrophoretic analysis of the mt DNA from three pairs of A/B lines are encouraging.

Nigeria

During 1984, the ICRISAT/Nigeria Program concentrated on the evaluation of materials developed in previous years. Varieties were entered in the national yield testing program, and in joint trials with the national millet breeding program, to evaluate promising new materials from both programs. All promising varieties and breeding lines were evaluated for their reaction to DM, ergot, and smut in disease nurseries at the Institute for Agricultural Research (IAR) at Samaru.

Yield Trials

National state trials, multilocational testing. Three new varieties from the ICRISAT/Nigeria program (ICNMV 8010, ICNMV 8012, and ICNMV 8032 together with 11 other entries were tested at 12 locations by state ministries and other national agricultural institutions. At 5 of the 12 sites, the trials were considered to have been satisfactorily conducted. At these five locations, the three selections performed well (Table 26). In trials over the past 3-4 years, ICNMV 8010 and ICNMV 8012 have yielded the same or higher than the improved local control varieties. The National Institute is interested in using these varieties again in multilocational testing in 1985.

ICRISAT/IAR joint national trials. We conducted three millet grain yield trials (AMYT 1-84, AMYT 2-84, and AMYT 3-84) with the IAR and the Lake Chad Research Institute. The major objectives were to obtain a more reliable

Table 26. Top-ranking pearl millet varieties at five locations, National State Trials, Nigeria[1], rainy season 1984.

Variety ranking	Trial location				
	Samaru	Kano	Mani	Dambam	Damaturu
1	SE 131[2]	ICNMV 8010[3]	ICNMV 8010	SE 2105	SE 13
2	ICNMV 18010	ICNMV 8012	ICNMV 8032	ICNMV 8032	SE 361
3	GDC	Nig Comp	SE 5	SE 360	ICNMV 8012
4	SE 45	SE 2105	SE 2106	SE 2105	SE 2106
5	Local	SE 2106	GDC	Local	1NNMV 8032
Trial yield range (kg ha^{-1})	2410-1580	5260-4730	4100-3010	2320-1640	4270-3350

1. From National Cropping Scheme Report 1984.
2. SE numbers are varieties developed by the Institute for Agricultural Research.
3. ICNMV numbers are varieties developed by the ICRISAT/Nigeria Program.

evaluation of the newly-developed cultivars from both the ICRISAT and IAR programs at six representative sites in the millet-growing areas of Nigeria, and to facilitate more rapid transfer of the ICRISAT improved selections to the national system.

The major problem common to all the experimental sites was bird damage, and the earlier-maturing entries were most badly affected. Useful results were obtained from only three of the six locations, Kano, Ngala, and Samaru.

AMYT 1-84. Three ICRISAT varieties (ICNMV 119, ICNMV 46, and ICNMV 70 yielded as well as the controls and best improved national program entries at the Samaru and Kano locations. Five other ICRISAT selections (ICNMV 10, ICNMV 37, ICNMV 12, ICNMV 40, and ICNMV 4 yielded as well as the national program entries at Kano. There were no varietal yield differences at Ngala.

AMYT 2-84. There were no differences in grain yield among varieties at any of the three locations.

AMYT 3-84 One ICRISAT selection (ICNMV 68) and two new IAR selections (SE 361 and SE 2106) significantly outyielded the Nigerian Composite at Samaru. In addition, eight other ICRISAT selections, ICNMV 72, ICNMV 39, ICNMV 43, ICNMV 141, ICNMV 55, ICNMV 9, ICNMV 36, and ICNMV 32 yielded as much as the Nigerian Composite. There were no significant differences in yields between varieties at Kano and Ngala.

Disease Resistance Screening

We work on disease screening in collaboration with the IAR millet pathologist. We conducted screening nurseries under sick-plot conditions at Samaru, to thoroughly screen many promising millet progenies and lines developed by the ICRISAT program for DM, ergot, and smut diseases.

Advanced lines screening nursery. Of 50 varieties screened, 24 entries showed very low incidence for the three major diseases, and 35 were rated low for DM incidence.

Selection nursery. Out of 270 progenies evaluated, 124 showed low levels of all three diseases. These progenies included: 52 base-parental selections, 33 entries from the previous F_1 crosses nursery, 29 entries from pollen parent selections, and 10 IMPS lines.

It was encouraging to note that amidst high DM, smut, and ergot pressures developed using infector rows and artificial inoculation, many lines showed resistance to these diseases.

Sudan

Objectives of the program are to identify and develop new genotypes with high yield potential and stability, resistance to drought, diseases, insects, and birds, that can perform better than the existing varieties grown by the farmers. We are making selections for early maturity, head compactness, and bristledness in breeding new genotypes.

Trials were grown at five locations-Kaba (El Obeid), Western Sudan Agricultural Research Project (WSARP) Farm (El Obeid), Kadugli, Umm Rakuba, and Nyertete, representing diverse growing conditions. Rainfall was far below normal at each location. The drought provided a difficult survival test for all our experimental material, the effect being particularly severe at our main breeding site, El Obeid (1984 rainfall 142 mm).

Plant Improvement

Inbreds and synthetics. We made 189 new variety crosses by combining local and exotic accessions representing disease-resistant, drought-resistant, and late-maturing groups. Twenty-two were exotic x exotic, 36 local x local, and 131 local x exotic. Crosses have been planted in the off-season nursery to advance one generation, and their F_2s will be studied in 1985. We evaluated 127 F_2 populations, and selected about 13 single plants from 55 crosses. Mansori, a local variety from eastern Sudan, and Bayuuda, a local variety from southern Darfur, appear to be good combiners, based on progeny selected from crosses on which they were parents. We studied 903 segregating progenies (F_3, F_4, F_5, and F_6), and five of them were found uniform, high-yielding, and agronomically desirable. These have been selected for use in national trials and in our exchange nursery. Seventy-five of these progenies contributed to the selection of 131 individual plants for future selection to develop inbreds and synthetics.

Hybrids. We evaluated five ICRISAT lines, five male-sterile selections from Ex-Bornu made in 1983, and three male-sterile lines from USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL). Male sterile Ex-Bornu was found to be better adapted to local conditions. We made 63 hybrids, utilizing Ex-Bornu and J 1623 as seed parents. These will be evaluated in 1985 to identify elite restorers and maintainers.

Populations. Our early-maturing bristled population with a mean grain yield of 186 kg ha^{-1} performed better than any material grown on the WSARP farm this year. We selected 298 plants to improve this population for uniformity in grain and glume colour. S,s will be produced in the off-season nursery. The mean grain yield of the selected plants was 135% higher than the mean of the population.

Fifty-one plants were selected from a Bulk Population for the 3rd cycle of selection. The selected plants were superior for grain yield to the MC_2 bulk by a margin of 270%. Two local varieties from southern Darfur, Wad El Lahaw, and Kori, after two cycles of selection are 7-10 days earlier than the original population and are now free of shibras. Kori C_2 bulk was found significantly better than the Kori C_0 bulk for head number, grain yield, and total dry matter. Kori C_2 bulk yielded 19% more than the original population.

We planted 875 accessions of local landraces and evaluated the progeny, recording agronomic data on 361 entries that survived to maturity.

Trials and Nurseries

We grew two Pearl Millet National Trials (PMNT 8A and 8B) in 1984. In PMNT 8A, seven entries, ISMI 8401, ISM1 8402, ISMI 8407, ISMI 8409, ISMI 8410, Bulk Population MC, Bulk, and Bristled Population MC, Bulk, were found promising and have been selected for re-evaluation. In PMNT 8B at Nertete, ICTP 8202 gave 30% more grain yield than the mean of Bayuuda, the local control. Other entries from PMNT 8B selected for re-evaluation in 1985 were MC-P8003, ICMV 82111, IVC-P8004, and ICMS 7817. Bristled Population and ICTP 8202

A farmer in North Kordofan, Sudan, showing heads of an ICRISAT-bred high-yielding pearl millet variety, Ugandi.

have been selected for on-farm experiments in 1985. Fifteen on-farm trials using Ugandi and local varieties were grown around El Obeid in association with INTSORMIL. Ugandi was found superior to the local varieties that generally did not produce grain because of the drought.

Plant selection was made in two entries (ICMI 84016 and ICMI 84021) from the 1984 exchange nursery and five entries from the 1983 exchange nursery (CMM 32 x Souna III, ICMS 7845 x IBV 8004, GIN 192-2 x D2 9043, R 16 x L 5053, and Togo 17 x Siria Korola). The majority of the entries in IMZAT, IPMAT, and PMAVT yielded no grain because of the severe drought. Data were recorded on total dry-matter production only for these trials.

Southern Africa

Research activities in pearl millet were initiated in 1984 by the regional SADCC/ICRISAT sorghum and millets improvement program based at Bulawayo, Zimbabwe. Requests for seed for regional testing were sent to 21 scientists around the world. There was a good response, as seed of over 2400 entries representing a diversity of accessions, breeding materials, and finished products were received by October. The entries were divided into 13 trials and nurseries which were then planted at as many as seven locations in five countries, Botswana, Malawi, Tanzania, Zambia, and Zimbabwe (Table 27).

It is anticipated that results obtained from these initial trials and nurseries will indicate the types of materials which are likely to perform well in the SADCC region. This information should make a significant contribution to ICRISAT's future research activities for pearl millet improvement in southern Africa.

Table 27. Pearl millet nurseries grown in Southern African Development Coordination Conference (SADCC) countries, main cropping season, 1984/85.

Trial/Nursery	No. of entries	Locations[1]
Synthetics	77	Matopos, Aisleby, Sebele, Ngabu, Hambolo
Elite varieties	18	Matopos, Aisleby, Kaoma, Ngabu, Hambolo
Hybrids	24	Matopos, Aisleby, Sebele, Ngabu, Hambolo
Populations	32	Matopos, Aisleby, Sebele, Ngabu, Hambolo, Kaoma
Disease-resistant lines/ Populations	38	Matopos, Aisleby, Sebele, Kaoma, Ngabu, Hambolo
Inbreds	621	Matopos, Kaoma, Aisleby, Hambolo
Germplasm accessions	1520	Matopos, Aisleby, Gwebi, Kaoma, Ngabu, Hambolo, Sebele
A and B lines (Tifton, Georgia)	50	Matopos, Aisleby, Kaoma
A and B lines and populations (Kansas State University)	40	Matopos, Aisleby
Varieties from Burkina Faso	14	Matopos, Aisleby
IMZAT	16	Matopos, Aisleby, Kaoma
Pearl Millet Exchange Nursery	75	Matopos, Kaoma
IPMAT	24	Matopos, Kaoma

1. Station locations: Sabele, Botswana; Ngabu, Malawi; Hambolo, Tanzania; Kaoma, Zambia; Aisleby, Gwebi; and Matopos, Zimbabwe.

Technicians working with the SADCC/ICRISAT program bagging heads of the first pearl millet trials grown at Bulawayo Sewage Farm, Aisleby, Zimbabwe, 1984.

Workshops, Conferences, and Seminars

Pearl Millet Scientists' Days

During the first week of April, pearl millet scientists met for 2 days at ICRISAT Center. About 35 pearl millet scientists from the Indian national program attended the meeting together with 14 scientists from ICRISAT. This was the first time a Scientists' Day had been organized to show cooperating scientists the dry-season millet crop and to give them a chance to select materials in this season. The event provided opportunity for interaction and discussion of common needs and problems among scientists, and for national program scientists to select ICRISAT lines and breeding materials.

Entomology Working Group

A one-day working group meeting for entomologists in Niger was sponsored by the ISC in Niamey, 27 April. It was attended by participants from ICRISAT, INRAN, and the Comite Permanent Inter-Etats de Lutte Contre la Secheresse dans le Sahel (CILSS) Integrated Pest Management Project.

Collaborative research on pearl millet pests was discussed and the meeting developed plans to conduct a multilocational trial on *Raghuva albipunctella* at five locations in Niger.

Third Regional Workshop of the Eastern Africa Sorghum and Millet Improvement Network

This workshop was held at Morogoro, Tanzania, 5-8 June 1984. There were 30 participants, half of them from the host country, and others from Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda, and Yemen (PDR). All participants were active workers in sorghum and millet research. Twenty papers were presented, seven on different aspects of the Tanzanian national sorghum improvement program, the remainder by country representatives who each reported on the sorghum and millet work in his country during the 1983/84 crop season. The results of the 1983 Eastern Africa Cooperative Sorghum Regional Trials (EACSRT) were presented and discussed.

The major recommendations of the workshop were to combine several cooperative sorghum regional trials in eastern Africa and to initiate in 1985 a special regional sorghum screening nursery of breeding lines from ICRISAT Center, Ethiopia, SAFGRAD/ICRISAT (Kenya), Tanzania, and Uganda. The proceedings of this meeting are available from the SAFGRAD/ICRISAT Regional Office, Nairobi, Kenya. The 4th Annual Regional Workshop will be held in Uganda in 1985.

Regional Workshop on Pearl Millet Improvement in West Africa

This regional workshop, sponsored by ICRISAT, was held at ISC, Niamey, 31 August to 4 September. The main objective was to bring together all scientists working on pearl millet improvement in national and regional programs in West Africa, and to review current pearl millet improvement research in the region. The workshop also provided an opportunity for participants to familiarize themselves with the objectives of ICRISAT's regional research on pearl millet improvement.

A total of 29 research workers from Benin, Burkina Faso, Cameroon, Chad, Gambia, Ghana, ISC, Ivory Coast, Mali, Niger, Nigeria, SAFGRAD, Senegal, Sudan, and Togo participated.

The program reviewed the role of national and regional organizations and ICRISAT/UNDP country programs. Topics of special interest including the conduct of exchange nurseries and yield trials were discussed, and the participants visited the ISC Research Station at Sadore and the INRAN Research Station at Kolo.

The workshop participants made several recommendations for pearl millet breeding in the region: they advocated a multidisciplinary approach to millet improvement, breeding adapted varieties, the improvement of local populations, and improvement of grain quality to include consideration of physical characteristics of grain. The need to screen for resistance to such stress factors as downy mildew, *Striga hermonthica,* insects, and drought as also emphasized.

Participants indicated that in association with the national programs, ICRISAT should play a key role in West Africa in the evaluation, maintenance, and exchange of genetic resources; organization of regional and inter-regional visits and workshops; and dissemination and exchange of current literature on pearl millet through the Sorghum and Millet Information Center.

Working Group Meeting on Cereal Nitrogen Fixation

A working group meeting on cereal nitrogen fixation was held 9-12 October at ICRISAT Center. Twenty-one scientists representing ICAR, Indian universities, and other Government of India research organizations participated in the meeting, together with seven members of ICRISAT staff. Eighteen papers covering current research findings and plans for future work by different research groups were presented in the main sessions. In addition to these working sessions, there were special sessions on methods of measuring nitrogen fixation associated with cereals, methods of enumerating and quantifying nitrogen-fixing bacteria, and on crop responses to field inoculation with nitrogen-fixing bacteria. In a concluding session, the participants emphasized the need for more standardized, uniform techniques for quantification studies, and more applied field work at different geographic locations. They also identified other priority areas for work on cereal nitrogen fixation. The proceedings are in preparation and will be available from Information Services, ICRISAT.

SADCC/ICRISAT Regional Workshop

A workshop was held in Harare, Zimbabwe, 22-25 October, to make plans for work in 1984/85 and to begin to generate information relevant to sorghum and millet in the SADCC region. Sorghum and millet workers representing a range of disciplines from all SADCC countries except Angola and Swaziland attended. Cooperators indicated the types of pearl millet nurseries and trials they were interested in growing during the 1984/85 main cropping season.

Looking Ahead

Physical stresses. Now that we have almost completed work on techniques to evaluate the ability of seeds to germinate and emerge under several problem seedbed conditions, we will shift our emphasis to using these techniques in the breeding program. This will include both routine testing of advanced materials and evaluating the response to selection for emergence in the composite breeding project.

Work on techniques to screen for post-emergence seedling survival and growth will continue, and when feasible these techniques will be used to evaluate breeding materials at the ISC.

Further emphasis in drought research will be on stress during flowering and grain filling, which has a much greater effect on grain yields than preflowering stress. Initial investigations will be on differences in ability to set grain under these conditions and on carbohydrate availability for grain filling.

Biotic stresses. Large scale field screening for resistance to DM, ergot, and smut at ICRISAT Center, and for rust at Bhavanisagar will continue, although we hope to increase reliability for rust screening at ICRISAT Center. Establishment of reliable DM screening in Niger will receive priority attention, and will involve sequential sowing with perfospray irrigation during both the rainy and off-seasons to determine the optimum time of sowing to coincide with a good disease epidemic. In addition, DM screening will also be attempted in the higher rainfall area of Gaya, and smut and DM screening will be attempted under higher natural humidity in the Niger River valley near Sadore.

We shall continue to organize the International Pearl Millet Disease Resistance Testing Program for DM, ergot, smut, and rust. However, we are likely to reduce somewhat the number of locations in India and we shall try to increase the number of locations in Africa. We hope to be able to identify the DM reaction types of more African pearl millets in West Africa and use this information to include more African pearl millets in our multilocational testing. We anticipate initiating a disease nursery at several locations in southern Africa.

Studies on pathogenic variability of the DM fungus and mechanisms of resistance to ergot will be continued with our collaborators at the University of Reading, and Imperial College, UK. Basic studies on various aspects of the biology of the four diseases will continue at 1CRISAT Center, and an effort will be made to produce sporangia for field inoculations at ISC.

Strategies have been developed with breeders to more fully utilize identified sources of disease resistance in the breeding program. Attempts to study inheritance of resistance to diseases will continue at ICRISAT Center.

We will initiate studies to develop stable and reliable techniques to ensure high stem borer and earhead caterpillar infestations to screen large pearl millet collections. We will use these studies to identify and utilize head characteristics that are vital in determining tolerance or resistance, and to screen a larger, and more representative collection of African germplasm accessions. We will also undertake more detailed studies on the biology and ecology of the earhead caterpillar to determine the key factors related to cessation of pupal diapause, and subsequent moth emergence. We also plan to make a detailed iventory of parasites and predators of both pests, possibly with the assistance of a collaborating institute specializing in such studies.

Microbiology. We will continue our long-term nitrogen-balance studies in the field with millet and forage grasses to estimate the amount of nitrogen fixed. We will also continue to use ^{15}N-based techniques to quantify the differences in nitrogen fixation associated with selected millet cultivars.

We will be studying the response of millet to inoculation with nitrogen-fixing bacteria at several locations and the effects of organic matter amendments on the inoculation responses. We will also report the establishment and persistence of inoculated nitrogen-fixing bacteria in the field.

We will continue field and pot tests on the efficiency of VAM isolates collected from Rajasthan. We will seek further confirmation of genotype differences in response to VAM inoculation in the field. Studies on the role of VAM inoculation in better utilization of rock phosphate will be emphasized. We hope to survey pearl millet growing in the SAT regions of West Africa for VAM status and for plant and soil phosphorus content.

Plant improvement. Emphasis on genetic resources utilization will be increased. Accessions with high seed mass will be fed back into the large-seeded gene pool, which will be improved by mass selection to generate materials for use in breeding programs at ICRISAT Center and elsewhere. Stable sources of very high DM resistance will be exploited in the genetic diversification project. New sources of major dwarfing genes will be introduced into breeding materials.

Inbreds identified from various breeding projects as having shown very high general combining ability will be crossed with existing B lines. Smut-resistant lines will be utilized to breed smut-resistant, male-sterile lines to diversify the genetic base of the male-sterile program. High-yielding d_2 dwarf populations will be utilized as sources of long heads (up to 36 cm) in male-sterile breeding. Mutation breeding, both cytoplasmic and genetic, will be used in the male-sterile breeding project.

More emphasis will be given in the pollinator project to using high-yielding progenies from the population improvement project.

We will continue to conduct IPMAT, participate in the AICMIP testing system, and distribute annual nurseries containing elite breeding materials. Seed will be supplied worldwide and relations strengthened with SADCC countries and INTSORMIL millet researchers.

We will begin selecting for smut and rust resistance in the population improvement project and will begin work on ergot resistance. We will investigate further procedures for making population varieties.

At the ISC evaluation of new accessions collected in Cameroon, Sierra Leone, Zambia, and Zimbabwe will be undertaken. Generation of new variability using adapted parental material will continue. Selected progenies will be used to form synthetics and superior population progenies to constitute varieties. Work on hybrids and the identification of new maintainer lines will continue. We will continue to evaluate yield trials and exchange nurseries originating from ICRISAT Center, the ICRISAT West African Program, and national programs in the region.

Screening techniques developed at ICRISAT Center for seedling establishment under drought stress and under high soil temperatures will be tested further and appropriate modifications will be made to enable large-scale screening of breeding material for better establishment under Sahelian conditions.

In Senegal in 1985, the advanced yield trial with new entries will be initiated in collaboration with the ISRA Millet Program. Selected synthetics and hybrids will be multilocationally evaluated in yield trials, and improved versions of IBV 8004 and Souna III will be compared with original bulks. The 401 inbred lines tested in 1984 will be re-evaluated to characterize morphological traits. The improvement of IBMV 8401 through limited backcrossing will continue.

In Sudan we will continue to conduct pearl millet national trials. Bristled Population MC_2 Bulk and KTP 8202 will be included in the on-farm testing program of 1985 in different millet-growing regions of the country. Multinational trials, evaluation of breeding materials, and progeny testing will continue. Researcher-managed on-farm trials will be conducted with selected material.

The Niger national program will be assisted by ICRISAT to multiply pearl millet varieties ITMV 8001, ITMV 8002, and ITMV 8304, recommended by INRAN for release in Niger in 1985. Furthermore, the Institut du Sahel will be given technical assistance in their efforts with demonstration trials in farmers' fields of ITMV 8001 and ITMV 8003. We hope to improve the performance of these varieties and others by selection to eliminate poorer plants within their populations.

In Nigeria, a number of newly-developed selections, from both the ICRISAT and IAR programs deserve, and will receive serious consideration by the national program as possible alternate varieties to the Nigerian Composite and/or possible replacement varieties for Ex-Bornu and the World Composite. Most of the new ICRISAT experimental varieties have advantages of earlier maturity, shorter plant height, and more productive tillering than the current improved varieties. A better and reliable testing system will be sought to determine the potential of these new selections.

Publications

Institute Publications

Andrews, D.J., and Harinarayana, G. 1984. Procedures for the seed production of pearl millet varieties. Information Bulletin no. 16. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 6 pp.

Journal Articles

Anand Kumar, K., and Andrews, D.J. 1984. Cytoplasmic male sterility in pearl millet *(Pennisetum americanum* [L.] Leeke): a review. Advances in Applied Biology 10:113-143.

Anand Kumar, K., Andrews, D.J., Jain, R.P., and Singh, S.D. 1984. Registration of ICMA-1 and ICMB-1 pearl millet parental lines with A1 cytoplasmic-genic male sterility system. Crop Science 24:832.

Bramel-Cox, P.J., Andrews, D.J., Bidinger, F.R., and Frey, K.J. 1984. A rapid method for evaluating growth rate in pearl millet and its weedy and wild relatives. Crop Science 24(6):1187-1191.

Giller, K.E., Day, J.M., Dart, P.J., and Wani, S.P. 1984. A method for measuring the transfer of fixed nitrogen from free-living bacteria to higher plants using $^{15}N_2$. Journal of Microbiological Methods 2:307-316.

Henson, I.E., Mahalakshmi, V., Alagarswamy, G., and Bidinger, F.R. 1984. Leaf abscisic acid content and recovery from water stress in pearl millet *(Pennisetum americanum* [L.] Leeke). Journal of Experimental Botany 35(150):99-109.

Henson, I.E., Mahalakshmi, V., Alagarswamy, G., and Bidinger, F.R. 1984. The effect of flowering on stomatal response to water stress in pearl millet *{Pennisetum americanum* [L.] Leeke). Journal of Experimental Botany 35(151):219-226.

Kanwar, J.S., Rego, T.J., and Seetharama, N. 1984. Fertiliser and water-use efficiency in pearl millet and sorghum in Vertisols and Alfisols in semi-arid India. Fertiliser News 29(4):42-52.

Krishna, K.R., and Dart, P.J. 1984. Effect of mycorrhizal inoculation and soluble phosphorus fertilizer on growth and phosphorus uptake of pearl millet. Plant and Soil 81:247-256.

Singh, S.D., Gopinath, R., Luther, K.D.M., Reddy, P.M., and Pawar, M.N. 1984. Systemic remissive property of metalaxyl against downy mildew in pearl millet. Plant Disease 68(8):668-670.

Soman, P., Peacock, J.M., and Bidinger, F.R. 1984. A field technique to screen seedling emergence of pearl millet and sorghum through soil crusts. Experimental Agriculture 20:327-334.

Subba Rao, K.V., and Thakur, R.P. 1983. *Tolyposporium penicillariae,* the causal agent of pearl millet smut. Transactions of the British Mycological Society 81:597-603.

Thakur, R.P., Rao, V.P., and Williams, R.J. 1984. The morphology and disease cycle of ergot caused by *Claviceps fusiformis* in pearl millet. Phytopathology 74:201-205.

Wani, S.P., Upadhyaya, M.N.,and Dart, P.J. 1984. An intact plant assay for estimating nitrogenase activity (C_2H_4 reduction) of sorghum and millet plants grown in pots. Plant and Soil 82:15-29.

Williams, R.J. 1984. Downy mildew of tropical cereals. Advances in Plant Pathology 2:1-103.

Conference Papers

Andrews, D.J., Mughogho, L.K., and Ball, S.L. 1984. Sorghum and millet production in Africa: problems and prospects with new varieties. Pages 85-90 *in* Proceedings of the CAB's First Scientific Conference, 12-18 Feb 1984, Arusha, Tanzania. Farnham Royal, Slough, UK: Commonwealth Agricultural Bureaux.

Gebrekidan, B. (ed.) 1984. Sorghum and millet improvement in eastern Africa: proceedings of the Third Regional Workshop on Sorghum and Millet Improvement in Eastern Africa, 5-8 June 1984, Morogoro, Tanzania. Nairobi, Kenya: SAFGRAD/ICRISAT Program. 255 pp.

Giller, K.E., Wani, S.P., and Day, J.M. 1984. Comparisons of the amount of nitrogen fixation associated with millet and sorghum cultivars by isotope dilution. Page 41 *in* Abstracts of the Third International Symposium on Nitrogen Fixation with Non-Legumes, 2-8 Sep 1984, Helsinki, Finland. Helsinki, Finland: The Finnish National Fund for Research and Development (SITRA).

Huda, A.K.S., Sivakumar, M.V.K., Alagarswamy, G., Virmani, S.M., and Vanderlip, R.L. 1984. Problems and prospects in modeling pearl millet growth and development: a suggested framework for a millet model. Pages 297-306 *in* Agrometeorology of sorghum and millet in semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Ramaiah, K.V. 1984. Physiological specialization of *Striga hermonthica* and crop specificity. Pages 58-65 *in* Third International Symposium on Parasitic Weeds, 7-9 May 1984, ICARDA, Aleppo, Syria. Aleppo, Syria: International Center for Agricultural Research in the Dry Areas.

Ramaiah, K.V. 1984. Patterns of *Striga* resistance in sorghum and millets with special emphasis on Africa. Pages 71-92 *in Striga:* biology and control: papers presented at a Workshop on the Biology and Control of *Striga,* 14-17 Nov 1983, Dakar, Senegal. Paris, France: ICSU Press, and Ottawa, Canada: International Development Research Centre.

Seetharama, N., Mahalakshmi, V., Bidinger, F.R., and Sardar Singh. 1984. Response of sorghum and pearl millet to drought stress in semi-arid India. Pages 159-173 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Wani, S.P., and Dart, P.J. 1984. Nitrogen fixation associated with sorghum and pearl millets. Page 92 *in* Abstracts of the Fourteenth Steenbock Symposium on Nitrogen Fixation and CO_2 Metabolism, 17-22 June 1984, Madison, USA. New York, USA: Oxford University Press.

CHICKPEA

Contents

Cover photo: Chickpea ICCC 32, the first kabuli type wilt-resistant cultivar identified for release in central India after 3 years of excellent performance in the All India Coordinated Trials.

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CHICKPEA

Our principal objective continues to be the development of improved cultivars and genetic stocks of desi- and kabuli-type chickpeas capable of higher and more stable yields in all types of cropping systems.

During the 1983/84 cropping season, our activities continued at three main locations, ICRISAT Center (18°N, 78°E, 800 mm mean annual rainfall), on short-duration desi types; Hisar (29°N, 75°E, 450 mm annual rainfall), in cooperation with Haryana Agricultural University (HAU), on long-duration desi and kabuli cultivars; and at Aleppo (36°N, 37°E, 340 mm annual rainfall), Syria, at our sister institute the International Center for Agricultural Research in the Dry Areas (ICARDA), on kabuli types for winter or spring sowing in the Mediterranean region, and South and Central America.

Our subsidiary testing centers included Gwalior (26°N, 78°E) in central India, and for off-season advancement and multiplication, Tapperwaripora (34°N, 75°E) in Kashmir, northern India, Sarghaya (36° N, 36° E), Syria, Terbol (34° N, 36°E), Lebanon, and Islamabad, Pakistan (34° N, 73°E). We acknowledge the contributions of the many cooperators who have made it possible to increase the number of international trials and nurseries distributed during 1984.

In India, where chickpea is only grown in the postrainy season, 1984 was not so favorable as 1983. At ICRISAT Center, rainfall in 1983, though above average, continued into October and early November, hampering seedbed preparation and causing considerable delay in sowing. Plant stands were reduced by collar rot and fusarium wilt making interpretation of data difficult in several experiments. *Heliothis* sp infestations, although less than in recent years, caused some damage to the crop at the podding stage.

At Hisar, rainfall during the growing season was lower than normal. The winter was very cool and dry, so ascochyta blight and botrytis gray mold did not appear. But severe salinity problems caused high plant mortality, making it impossible to analyze most of our experimental results. *Heliothis* sp populations were below normal and caused only slight damage at the podding stage.

In Syria, the winter was dry and warm, total winter rainfall (200 mm) was 30% less than normal, which adversely affected growth of the winter-sown crop and also caused a decrease in the area of spring-sown crop. Drought conditions further extended into the spring and caused more yield reduction in spring-sown than in winter-sown chickpeas. Because of the widespread drought many of our trials were affected, and in some, no valid data could be recorded. These trials will be repeated in 1985.

Physical Stresses

Drought Tolerance

Chickpeas are generally grown on stored soil moisture in the semi-arid tropics (SAT) and are subjected to varying degrees of soil and atmospheric drought during the growing season. Limited rains during the crop season to some extent reduce the intensity of soil drought. In some areas, such as the SAT parts of peninsular India, chickpea growth and yield is severely restricted by lack of water. Alleviation of this stress by irrigation more than doubles chickpea yields (ICR1SAT Annual Report 1978/79, p.123). Where irrigation facilities are limited, increased and stable yield levels can be achieved only by the selection and breeding of drought-tolerant cultivars. We screened a large number of new chickpea accessions at ICRISAT Center for drought tolerance in nonreplicated field trials this year. The drought tolerance index was computed by adopting a regression approach (ICRISAT Annual Report 1979/80, pp. 82-84). We selected 12 susceptible, and 12 tolerant genotypes and tested them for drought tolerance in a replicated trial on a Vertisol and an Alfisol at ICRISAT Center. We measured distinct genotypic differences. There was a similar separation of the most tolerant and the most susceptible genotypes on Vertisols and Alfisols. Drought tolerance was not associated with low mean yield because the nonirrigated yield of the most tolerant genotype (1100 kg ha^{-1}) was comparable to that of Annigeri, the best-adapted cultivar of the region. Some of the promising genotypes will now be tested in yield trials in Vertisol fields differing in soil depths and water-holding capacities.

Table 1. Effect of different initial soil-moisture contents at 0-10 cm soil depth, created by sowing at different times after irrigation, on chickpea seedling emergence (%) at 16 days after sowing (DAS) on a Vertisol, ICRISAT Center, 1983/84.

Sowing date	Soil moisture at sowing (%)	Seedling emergence (%)[1]
30. 12.83	24.5	87
10. 1.84	24.3	86
24. 2.84	21.6	72
21. 3.84	20.6	57
SE	+0.22	+2.9

1. Average for 100 genotypes.

Germination from Limited Seedbed Moisture

One of the major reasons for low yields in farmers' fields is poor and nonuniform plant stands. This problem is primarily caused by nongermination of viable seeds due to insufficient soil moisture in the seedbed. We have previously described a field method to screen for chickpea genotypes that have a greater-than-average ability to germinate from seedbeds with receding soil moisture (ICRISAT Annual Report 1983, p. 122). We screened 100 genotypes by this method, using different sowing dates to create different initial soil-moisture contents in the top 10cm of soil. There was less emergence at lower soil-moisture levels (Table 1). The amount of moisture in the top 10 cm of soil accounted for 98% of the variability in plant stand. We found genotypic differences associated with this response and further studies are in progress to relate plant-stand establishment to yield.

Low-Temperature Tolerance During Flowering and Pod Filling

In regions where night temperatures are low during the flowering and pod-filling stages of chickpea development, such as in northern India, flowers abort and no pod set occurs (ICRISAT Annual Report 1978-79, p. 126). We have identified lines in breeders' segregating populations which set pods at such low night temperatures. However, these genotypes are not good agronomic types and produce very low yields. We are now incorporating this cold-tolerance character into suitable agronomic backgrounds.

Biotic Stresses

Diseases

Surveys

We continued disease surveys in Nepal, Pakistan, USA, and parts of India. In Nepal, botrytis gray mold *(Botrytis cinerea)* was very common in most of the chickpea areas, especially where chickpea was grown after lowland rice. Rust (*Uromyces ciceris-arietini)* was important in chickpea grown in submontane areas, whereas wilt (*Fusarium oxysporwn* f.sp *ciceri)* was observed at a low frequency. Stunt (pea leaf-roll virus) was observed at Pakhribas, District Dhankuta, Nepal. In Pakistan, unlike the past three seasons, we did not observe any natural incidence of ascochyta blight *(Ascochyta rabiei)* in farmers' fields. However, stunt, wilt, and root rot pathogens, in that order, were important in chickpea trials at experiment stations and in farmers' fields. Salinity was important in Sind Province wherever the water table was high. In the USA, a severe attack of ascochyta blight was observed in patches in a farmer's field near Genesee, Idaho. Damping-off (*Pythium ultimum*) was common at the Central Ferry Research Farm near Pullman, Washington. In western India, stunt was the most important disease followed by wilt. The incidence of stunt was unusually high (>30%) in northern India.

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

Screening for resistance. We continued to screen a large number of genotypes and breeding materials for wilt resistance in a wilt-sick plot. Of the 361 new germplasm accessions screened, 16 lines had <20% wilt incidence. Two kabuli lines, ICC 5363 and ICC 11195 were found promising in the 2nd year of screening.

We confirmed resistance in 70 wilt-resistant lines, identified through field screening, by pot screening in a screenhouse. We have now identified a total of 128 wilt-resistant lines, including 58 lines identified earlier.

Breeding for fusarium wilt resistance. We made 26 crosses between wilt-resistant and short- and long-duration desi and kabuli cultivars. We attempted 11 backcrosses to transfer wilt resistance to ILC 482, ILC 484, and other released Indian cultivars of short, medium, and long duration.

At ICRISAT Center, we screened 52 F_2 populations and 2326 F_3 progenies/populations in a wilt-sick plot and selected 1300 single plants and 182 progenies. We evaluated over 500 F_4 and more-advanced generation lines in normal plots; 792 single plants and 105 lines were selected for further testing. We attempted to compare a total of 144 wilt-resistant desi and kabuli lines in replicated tests, but the plant stands were so severely affected by *Sclerotium rolfsii,* that the results could not be analyzed. All the trials will be repeated in 1985.

At Hisar, we screened 24 F_2s and 318 F_3 progenies/bulks in wilt-sick plots and selected 1500 single plants. We evaluated almost 400 F_4 and more-advanced generation lines/bulks in normal fields, and selected 277 single plants and 97 lines; the most promising of these will be tested in replicated trials next year.

From preliminary and advanced yield trials, 10 entries (Table 2) will be contributed by ICRISAT to the International Chickpea Screening Nurseries (ICSNs) and one to the International Chickpea Cooperative Trial (ICCT).

Inheritance studies. We confirmed our earlier observation (ICRISAT Annual Report 1983, p. 124) that a 3rd independent dominant gene confers late wilting in cultivar H 208. Studies of the association of flower color with wilt reaction to race 1 of *F. oxysporum* f.sp *ciceri* showed that at least one of the loci governing flower color was independent of two of the loci conferring wilt resistance, and that the locus for flower color segregated independently of flower number per node.

Biology and epidemiology. Further studies indicated that *F. oxysporum* f.sp *ciceri* survived for 72 months in soil in which stubble from wilted plants was buried in March 1978. The fungus obviously survived for more than 6 years, but we have now terminated the experiment.

We began a study on mechanism(s) of resistance to chickpea wilt. Root exudates from wilt-resistant chickpea plants inhibited spore germination in *F. oxysporum* f.sp *ciceri.* Further work is in progress.

Other Soilborne Diseases

Screening for multiple soilborne diseases. Wilt-resistant germplasm accessions, breeding lines, and lines received from our cooperators in India were screened at ICRISAT Center in a plot containing the following pathogens, in order of prevalence: *F. oxysporum* f.sp *ciceri, Rhizoctonia bataticola, Sclerotium rolfsii, F. solani,* and *R. solani.*

Nine wilt-resistant germplasm selections identified in this trial were also resistant to multiple soilborne diseases. Of the six selected lines that

Table 2. Characteristics of promising wilt-resistant desi chickpea lines in trials at ICRISAT cooperative research centers, Hisar or Gwalior, 1983/84.

Line/Cultivar	Days to 50% flowering	100 seed mass (g)	Seed yield (kg ha^{-1})
ICCX 790068-29P-1P-1P-BT-BH	69	13.7	1670
ICCX 761889-BH-BH-5H-BH	76	10.6	1680
ICCX 752306-2P-1P-BP-1H-BH	80	12.7	1600
Control			
H 208	72	11.4	1570
SE	+ 1.6	+0.36	+ 135
ICCX 752243-4H-2H-BH-2H-BH	87	13.4	1180
Control			
H 208	76	12.7	410
SE	+2.0	+0.97	+ 164
ICCX 750736-15H-BP-1P-BH	84	12.1	1550
ICCX 760068-10P-1P-2P-BT-BH	80	14.7	1650
Control			
H 208	73	12.5	1270
SE	+2.0	+ 1.45	+154
ICCX 780215-67T-2P-1P-BP	72	12.1	1440
ICCX 780215-67T-1P-1P-BP	76	11.3	1310
Control			
H 208	73	12.6	670
SE	+ 1.6	+0.93	+ 145
ICCX 750954-2H-BP-1P-2H-BP	96	16.5	1600
ICCX 750744-13H-BH-1P-2H-BH	84	13.5	1460
Control			
H 208	77	13.8	830
SE	+ 1.3	+0.51	+ 199

showed potential resistance to both *Heliothis* and wilt, three showed <10% mortality from wilt and root rots. Eleven kabuli lines were resistant to wilt and root rots.

Ascochyta Blight *(Ascochyta rabiei)*

We continued screening for resistance to ascochyta blight in isolation plant propagators in a greenhouse at ICRISAT Center, and found the 29 lines reported resistant at ICARDA to be susceptible. Further, all chickpea accessions with resistance to the other diseases tested were also susceptible to ascochyta blight. Work on this disease by our scientists at ICARDA is reported elsewhere in this report.

Breeding for resistance. We made 18 crosses between ascochyta-resistant parents and long-duration cultivars. Seventeen F_2 populations from earlier crosses were screened by ICARDA in Syria and 13 populations in the joint HAU/

ICRISAT ascochyta blight screening nursery at Hisar in India. F_2s and more-advanced generation progenies were also screened and advanced at HAU, Punjab Agricultural University (PAU), and Himachal Pradesh Agricultural University in northern India. Resistant plants were selected at all locations and advanced to the next generation.

Botrytis Gray Mold *(Botrytis cinerea)*

We continued to screen germplasm accessions with known resistance to other diseases in isolation plant propagators, but did not find any that were resistant. We have identified 28 lines with moderate resistance to botrytis gray mold through laboratory screening at ICRISAT Center during the last 2 years. Of these, the 16 (ICC 121, 1069, 1084, 1093, 1102, 2165, 3540, 4014, 4055, 4063, 4065, 4074, 4075, 6671, 8383, and ICCL 80004) that were screened in the botrytis gray mold nursery at Pantnagar (Uttar Pradesh, India) were found field-resistant.

We continued to screen chickpea accessions and breeding material for resistance to botrytis gray mold in the nursery raised in collaboration with scientists at the G.B. Pant University of Agriculture and Technology at Pantnagar. Of the 2000 accessions screened, 159 were resistant and will be retested during the next season at Pantnagar, and also in isolation plant propagators at ICRISAT Center.

Breeding for resistance. We screened 30 F_2, 56 F_3, and 41 F_4 populations of earlier crosses between botrytis-resistant lines and adapted cultivars. We selected 43 F_3, and 37 F_4 bulks for yield evaluation and single-plant selection.

Stunt (Pea Leaf-Roil Virus)

During the 1983/84 season, we observed a high incidence (>30%) of chickpea stunt in farmers' fields in northern and western India. In our opinion this represents an alarming increase in the incidence of a disease that has until now been considered economically unimportant. This increase was also reflected in the stunt nursery at Hisar where incidence in the susceptible controls averaged 84% (range 61 to 100%).

Of the 339 new germplasm accessions tested for stunt resistance, only one (ICC 1556) remained free from stunt, five (ICC 114, 959, 1165, 1187, and 1592) showed <10%, 14 showed <20%, and the remaining 319 showed >20% stunt. Only one (ILC 183) of the 35 accessions with moderate resistance to ascochyta blight showed <20% stunt; the remainder were moderately to highly susceptible. Of the 15 accessions with moderate resistance to ascochyta blight and botrytis gray mold, only one (ICC 8383) showed <10% stunt. Of the 144 accessions/lines with resistance to wilt, one (ICC 10466) remained free from stunt, three (ICC 3354, ICCL 81014, and ICCL 81254) showed <10%, and nine showed <20% stunt; all the remaining 131 were highly susceptible. Of the 97 entries in the International Chickpea Trials, two (ICCL 83406 and ICCL 83428) remained free from stunt and one (ICCL 82403) showed <10% stunt. All the entries showing <20% stunt will be retested during the coming season.

Breeding for resistance. We screened 222 F_3 and 156 F_4 to F_6 progenies/bulks in the stunt nursery at Hisar and selected 166 single plants. Twenty-three of the most promising lines were bulked for testing in replicated trials next year.

Nematode Diseases

Survey of chickpea fields at ICRISAT Center. We investigated five Vertisol fields at ICRISAT Center for the presence of plant parasitic nematodes, and found cyst (*Heterodera cajani* and *Heterodera* sp), lance *(Hoplolaimus seinhorsti),* lesion *(Pratylenchus* sp), reniform *(Rotylenchulus reniformis),* spiral (*Helicotylenchus indicus* and *H. retusus),* and stunt (*Tylenchorhynchus* sp) nematodes. These genera are proven pathogens of various crops and can cause considerable yield losses. In Vertisol fields artificially infested with *F. oxysporum* f.sp *ciceri,* where chickpeas had been grown in the postrainy season for the past 5 years, but which had been fallow in the rainy season for the past 10 years, nematode populations were low, except for an unidentified species of *Heterodera.* Nematode populations were highest in fields in which sorghum and various other crops had been grown during the past 5 years. The unidentified cyst nematode found on one Vertisol field is different from those previously reported on chickpeas, and efforts to identify the species are in progress.

Multiple disease resistance. Identification of sources of multiple disease resistance has been one of the objectives of chickpea pathology at ICRISAT. For three seasons now, lines we have identified as resistant to wilt *(F. oxysporum)* and root rots *(R. bataticola, R. solani, S. rolfsii,* and *F. solani)* have been screened against ascochyta blight, botrytis gray mold, colletotrichum blight, and stunt. Table 3 shows the progress in the identification of multiple disease resistance in the 1983/84 season.

Cooperative Disease Nurseries

International Chickpea Root Rots/Wilt Nursery (ICRRWN). The 75 entries in the 1982/83 ICRRWN were sent to 25 locations in 18 countries. Results are reported in Pulse Pathology Progress Report No. 33, copies of which, along with other program-level publications, are obtainable from the Pulses Improvement Program, ICRISAT.

International Chickpea Stunt Disease Nursery (ICSDN). The 20 entries in the 1983/84 ICSDN were sent to ten locations in six countries. Results are reported in Pulse Pathology Progress Report No. 38,

Table 3. Multiple-disease resistant lines of chickpea up to 1983/84 season.

Lines with combined resistance/tolerance to :	Line number
Three diseases	
Wilt, dry root rot, and black root rot	ICC 12237, 12269
Wilt, dry root rot, and stunt	ICC 10466
Two diseases	
Wilt and dry root rot	ICC 925, 11315, 12241, 12257, 12268, 12270, 12271, 12273, 12428K[1], 12430K, 12435K[2], 12437, 12444, 12450, 12454, 12460, 12467, 12472
Wilt and black root rot	ICC 11313, 11316, 11317, 11320, 11324, 12236, 12237, 12239, 12242, 12245, 12249, 12255, 12256, 12258, 12259, 12269, 12274, 12275
Wilt and botrytis gray mold[3]	ICC 11321[3] ICCL 80004
Wilt and stunt	ICC 3354
Wilt and ascochyta blight[3]	ICC 3935
Wilt and sclerotinia stem blight[3]	ICC 858, 959, 4651, 4918, 6671, 6680, 8933, 9001
Botrytis gray mold and ascochyta blight[3]	ICC 1069
Ascochyta blight and stunt	ICC 693[4] ILC 183
Botrytis gray mold and stunt	ICC 8383
Dry root rot and stunt	ICCL 81014

1. K = Kabuli.
2. Resistant to the ICARDA *Ascochyta rabiei* isolate.
3. Tolerant to the Hisar isolate.
4. Tolerant to the Indian Agricultural Research Institute (IARI) *Ascochyta rabiei* isolate.

Breeding For Multiple Disease Resistance

Wilt and root rots. To incorporate root rot resistance into Annigeri, we screened 149 F_3 progenies in the multiple soilborne-disease screening nursery at ICRISAT Center and selected 215 single plants for further screening.

Wilt and ascochyta blight. We made 31 single and 49 three-way crosses between wilt and ascochyta-resistant parents, and adapted desi and kabuli cultivars.

Nineteen F_2, and two F_3 populations of earlier crosses were screened in a wilt-sick plot at ICRISAT Center and their respective F_3 and F_4 single-pod descent bulks will be screened in the ascochyta blight nursery at HAU, Hisar.

Wilt and stunt. We crossed ICCC 10, a cultivar found resistant to stunt and wilt, with the high-yielding north Indian cultivars, Pant G 114, GL 769, GC 588, H 75-35, and GNG 146.

Ascochyta blight and stunt. We grew 10 F_1s from crosses involving ascochyta- and wilt-resistant genotypes at ICRISAT Center and screened 20 F_2 populations in the stunt nursery at Hisar, where 242 single plants were selected for screening in the ascochyta blight nursery.

Ascochyta blight and botrytis gray mold. At Hisar, two replicated trials comprising 69 F_3 bulks were adversely affected by salinity and will be repeated next year. Thirteen F_4 bulks of crosses, earlier found promising under natural ascochyta and botrytis epidemics were grown at Hisar and 542 single plants selected.

Ascochyta blight, wilt, stunt, and botrytis gray mold. We made ten crosses to combine resistance to all four diseases and 15 to the first three diseases listed.

Insect Pests

Surveys

Heliothis armigera **attacking chickpea. Our surveys showed this is the major pest in chickpea-growing areas in Southeast Asia.**

Heliothis armigera was, as usual, the most widely-encountered insect pest on chickpea crops in all the areas we visited, but its populations were very variable. Many farmers' fields were virtually free from infestation while others suffered severe damage. In southern India, damaging infestations occurred during both the vegetative and podding stages of the crop. In northern India this pest was of importance only during the podding stage. In general there were fewer attacks on the crop in 1983/84 than in recent years.

Infestations of other insect pests were sporadic and localized. As in most years, there were reports of damage by the cutworms *(Agrotis* spp) from low-lying areas in central India. In some areas of northern India there were unusually large invasions of *Aphis craccivora.*

Heliothis armigera was the only insect pest noticed on chickpeas during a tour of Southeast

Asian countries. In the chickpea-growing areas around the Mediterranean, the leaf miner, *(Liriomyza cicerina),* is usually the most damaging insect pest, but it appears restricted to Europe and western Asia.

Heliothis armigera

Host-plant resistance. Although the incidence of this pest was relatively low at ICRISAT Center in 1983/84, particularly during the podding stage of chickpea, the open field host-plant resistance trials were again very successful. Our resistant and susceptible selections were clearly distinguishable during both the vegetative and podding stages.

Selection work on chickpea has now entered a new phase. In the first few years, work concentrated on the available germplasm accessions and we screened more than 12 500. Subsequently we confirmed resistance of several selections in a series of replicated tests over several seasons. Some of these selections have been successfully tested at several locations. These resistant genotypes were passed on to breeders who made crosses that were intended to intensify the available resistance and to combine it with other useful traits. In 1983/84 the screening work switched almost entirely to the segregating progenies produced from the crosses. In addition, all advanced genotypes from the breeding and pathology subprograms are being screened in the pesticide-free area at ICRISAT Center to ensure that ICRISAT does not unwittingly pass on any genotypes that are highly susceptible to insect pests.

The search for resistance to *H. armigera* has been most successful in short-duration genotypes that are well adapted to southern India. The longer-duration genotypes that thrive in northern India do not yield well at ICRISAT Center, even though they suffer little pod damage. This is because *H. armigera* populations are generally low in late February when such genotypes form pods. Consequently the screening of long-duration chickpeas has not been very successful at ICRISAT Center. Attempts to screen for resistance at Hisar have been thwarted by a series of crop failures, caused by diseases, weather, and salinity. However, some long-duration genotypes, originally selected at ICRISAT Center, including ICC 10243, were found to retain their resistance and yield well in trials at Hisar in the 1983/84 cropping season.

Breeding for resistance. We continued screening material against *Heliothis* both at ICRISAT Center and at Hisar. We made 67 crosses involving new sources of resistance with the established short-, medium-, and long-duration desi and kabuli cultivars, and also among the confirmed resistant lines to accumulate resistance genes. These crosses included two diallel series, one each of desi and kabuli types in addition to a line x tester for the kabulis. We also made 13 crosses to incorporate wilt resistance into the *Heliothis*-resistant lines.

The two F, diallel studies of 5 x 5 and 4 x 4 among adapted, borer-resistant, and susceptible desi parents of short duration confirmed again that variation for borer damage was predominantly additive. However, in the 5 x 5 kabuli diallel study, nonadditive gene effects seemed to be more important.

We screened 28 F_2 and 6 F_3 populations, and 1542 short- to medium-duration F_3 to F_6 progenies in the pesticide-free area at ICRISAT Center. A total of 978 F_4 to F_6 long-duration progenies were grown under similar conditions at Hisar. We selected 1340 single plants and individually bulked 37 superior progenies at ICRISAT Center, and also selected 1056 plants and 46 progenies at Hisar. Since most of the *Heliothis-resistant* lines are susceptible to *Fusarium oxysporum* f. sp *ciceri,* we screened one set each of F_3 and F_4 progenies in the wilt-sick plot at ICRISAT Center and only F_4 progenies at Hisar. Most of these succumbed to wilt but we selected 150 plants from the 105 surviving progenies at ICRISAT Center, and 140 plants from 92 progenies at Hisar.

The short- and medium-duration lines bulked at ICRISAT Center were tested for yield performance in the pesticide-free area. Their yields and *Heliothis* damage percentages were compared with resistant and standard controls. Two short-duration lines gave higher yields than ICC 506, the highest-yielding resistant control. These lines were also less damaged by *Heliothis.* In the medium-duration trial two lines also outyielded K 850, the standard control, and showed substantially less *Heliothis* damage. The resistant control 7341-8-1B-BP-EB had low damage but yielded poorly. This was the first such trial conducted on lines from the resistance breeding program. The significant positive correlations in damage between the F_4 and F_5 generations tested in the two consecutive crop years, 1982/83 and 1983/84, have further confirmed the dependability of our selection approach.

Mechanisms of resistance. We continued collaborative studies with the Max-Planck Institute for Biochemistry in Munich, Federal Republic of Germany. Tests in this year showed leaf exudates of plants grown at ICRISAT Center were generally four times more acidic than those of the same genotypes grown at Hisar. However, the exudate acidity of each genotype grown at both locations was highly correlated. The previous observation that resistant cultivars tend to have more acid exudates was generally confirmed, but there were several exceptions, so we suspect that other mechanisms are also involved in resistance. Field and laboratory studies confirmed that there is a marked preference by the moths to lay their eggs on susceptible genotypes, both during the vegetative and podding stages. There also appeared to be a preference for the pods of a susceptible genotype when these and pods from a resistant genotype were offered to larvae in laboratory tests. Work on the chemicals involved in chickpea resistance to *Heliothis* has been intensified at the Max-Planck Institute.

In a field experiment, all larvae were removed from alternate plants and alternate rows following counts at the end of each week. In these counts there were no consistent differences between the numbers of large larvae found on the plants and rows from which the larvae had been removed 7 days earlier, and those on which the larvae had been left undisturbed. This was good evidence that there was considerable movement of larvae from plant to plant, and from row to row. This is of importance in developing a methodology to screen single plants from segregating populations for resistance, particularly where oviposition nonpreference is involved.

Aphis craccivora

This aphid species has been determined as the major vector of pea leaf roll virus that causes stunt disease in chickpea. The disease has been recorded not only in India, but also in most other countries where chickpea is an important crop. This year there was an unusually severe incidence of stunt disease at Hisar. ICRISAT entomologists and pathologists initiated a joint study of this disease and its vector there. Sticky and water traps, developed following advice from the University of Illinois, were placed in stunt-susceptible chickpea plots surrounded by, and interspersed with, a variety of other legumes known to act as *A. craccivora* hosts. Trap catches showed that there were aphid dispersal flights from early November, but with a large peak in early December (Fig. 1). From late December to mid-March very few aphids were caught in the traps but there was another peak of catches at the end of March. Observations on the legumes indicated that cowpea (*Vigna unguiculata)* was the major host for this aphid. Mung bean (*Vigna radiata),* urd bean (*Vigna mungo),* and lentil (*Lens culinaris)* also sustained large populations of the insect. Aphids were found on some chickpea plants from the seedling stage in early November, and by the end of that month almost all the plants that we examined were infested. Stunt disease symptoms were noticed in a few plants in early November and there was a steady increase until March, when 90% of the plants showed symptoms.

Integrated Pest Management

In a series of trials at ICRISAT Center this year chickpea yield increases resulting from insecticide (endosulfan) use ranged from 14 to 18%. These increases were less than those recorded in most previous years, reflecting the relatively low infestations of H. *armigera* on the crop this year.

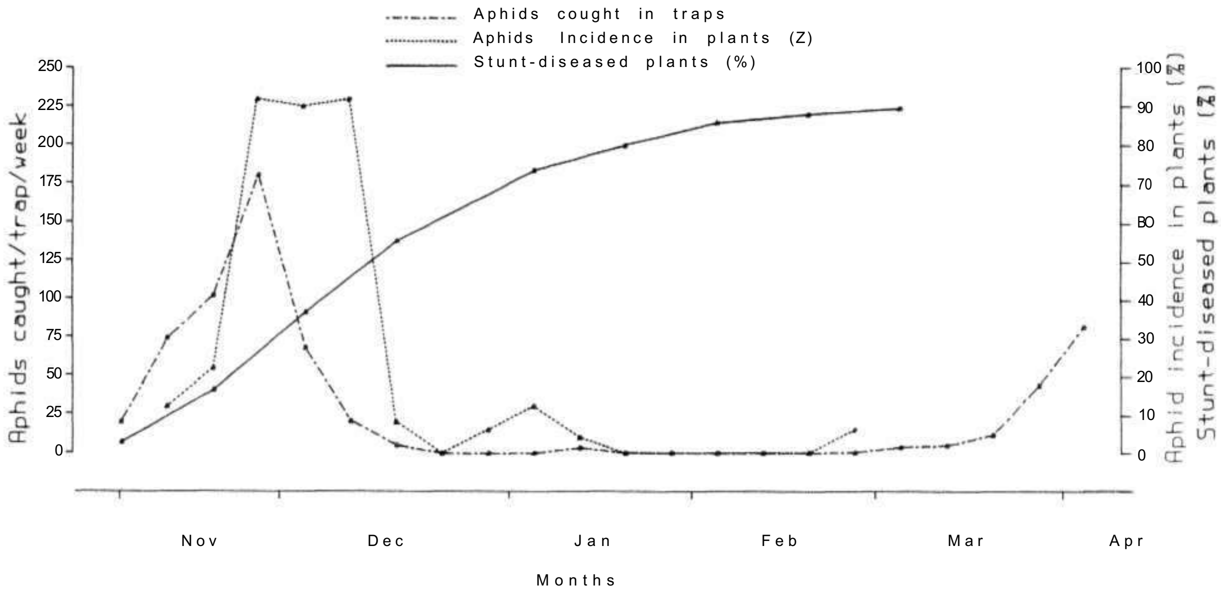

Figure 1. Weekly trap catches of aphids *(Aphis craccivora),* aphid incidence (%), and stunt disease progression in chickpea crops at Misar. 1983/84.

On the short-duration cultivars, most of the yield increase was associated with insecticide applied during the podding stage. In the longer-duration cultivars, insecticidal protection during the vegetative stage was most productive as pest populations were low when crops of this duration were podding.

Attempts to estimate the economic threshold levels of *H. armigera* larvae by releasing known numbers of larvae on each plant in caged test rows demonstrated the difficulties encountered in such experiments. Only a few of the larvae placed on each plant could be found 2 weeks later. Within one week of placing twelve 3-day old larvae on each plant, 84% had disappeared. Greater success was achieved when 7-day old larvae were placed on the plants, as up to 70% of these could be found a week later. We found no significant differences in percentage pod damage or in yield loss among the treatments in which a range of two to twelve larvae were placed on each plant. The percentage of pods damaged on these artificially-infested plants ranged from 15 to 26% and the yield losses, when compared with pest-free plants, ranged from 0 to 24%. It is essential that we develop a methodology to determine economic threshold levels, if insecticides are to be intelligently used as part of a pest management package for this crop.

Studies of the natural enemies showed relatively low levels of parasitism in the H. *armigera* larvae collected from chickpea at ICRISAT Center this year. *Campoletis ehlorideae* was the most common parasite, being recorded from 10.5% of the small larvae collected. Dipteran parasites, mainly *Carcelia illota,* emerged from 5% of the large larvae. Observations confirmed that the proportion of green larvae surviving on green plants were significantly greater than those surviving on red-colored chickpeas. Previous trials have shown that predators, particularly birds, can substantially reduce the populations of large larvae on chickpea (ICRISAT Annual Report 1983, p. 129). Green larvae feeding on green plants appear to have a selective advantage in being less visible to predators.

Biological Nitrogen Fixation

Rhizobium Collection

The ICRISAT collection continued to be a source of strains for inoculant manufacturers and research workers in India and elsewhere, and we despatched 284 units of *Rhizobium* strains as peat inoculants or agar slopes.

Nitrogen Fixation

In collaboration with Rothamsted Experimental Station, UK, and the Regional Agricultural Research Station of Jawaharlal Nehru Krishi Vishwa Vidyalaya at Morena, Madhya Pradesh, India, we carried out a ^{15}N trial to estimate the contribution of biological nitrogen fixation to the total N harvested by the chickpea crop. An inoculated, high-nodulating chickpea cultivar, K 850, was used as the test plant and barley, linseed, and a noninoculated low-nodulating chickpea, G 130, were nonfixing control crops. The native chickpea *Rhizobium* population in the soil was $<100 g^{-1}$ soil. We applied ^{15}N-labelled ammonium sulphate at the rate of 5.991% N atom excess (a.e.) to the test crop and 1.986% N a.e. to the control crops on 4.5 m^2 in the center of each 135 m^2 plot. We used the 'A' value method to calculate the amount of N fixed by the test crop. Nodule number, nodule weight, and nitrogen fixation by K 850 at 58 days after sowing (DAS) was significantly superior to G 130 (Table 4). Growth of G 130 was slightly better than that of K 850; this was probably due to its receiving more fertilizer N.

The ^{15}N-la belled plots were harvested at 97 DAS. The nonlegumes produced more dry matter, utilized fertilizer N better, but accumulated less total N than the two chickpea cultivars (Table 5). When used as nonfixing controls, barley and linseed gave similar estimates for proportion and amount of N fixed by K 850 (Table 5). However, as G 130 was able to fix some N it proved to be unsuitable for use as a nonfixing control.

Soil Moisture and Nodulation

We conducted a pot study on the effect of seven different levels of soil moisture on nodulation in an Alfisol and a Vertisol. Watering on alternate days to achieve a given moisture level was done by pouring required amounts of deionized water, determined by weight, into saucers placed below pots. Thus at each level we achieved a gradient of moisture from the base of each pot to the seed surface. Germination was poor at 12% moisture in the Alfisol and very poor at 15%, 20%, and 25% moisture in the Vertisol, resulting in only 1-3 plants per pot in these treatments while most other pots had four plants per pot.

Plants were harvested 32 DAS. In the Alfisol, nodule number and mass increased with soil moisture content, with the largest increase occurring at the highest moisture level (Fig. 2). In the Vertisol, an increase in these parameters occurred over the entire soil moisture range examined. It needs to be confirmed as to whether poor plant stand affected these parameters.

Screening for Nodulation and Nitrogen Fixation

From our field studies over several years and at different locations we have identified chickpea cultivars that are consistently high- or low-nodulating (ICR1SAT Annual Report 1980, pp. 134-136). However, superior nodulation does not

Table 4. Nodulation and N_2- fixation by chickpea at 58 DAS in ^{15}N-trial, Morena, India, 1982/83.

Cultivar	Nodule number plant^{-1}	Nodule dry mass plant^{-1} (mg)	N-fixation (μM C_2H_4 plant^{-1} h^{-1})	Shoot dry mass plant^{-1} (g)
K 850 (inoculated + 10 kg N ha^{-1})	35	87	5.5	8.5
G 130 (noninoculated + 50 kg N ha^{-1})	3	16	1.1	9.9
SE	+2.4	+10.9	+1.12	+0.66

Table 5. Total dry-matter yield and uptake of N and ^{15}N by chickpea, linseed, and barley at 97 DAS, Morena, India, 1982/83.

Treatment	Total dry matter (kg ha-')	Total N uptake (kg ha-')	Atom % ^{15}N excess	Fertilizer recovery (%)	K 850 N content derived from fixation (%)'	N fixed by K 850 (kg ha-')
K 850 (inoculated + 10 kg N ha^{-1})	2040	47	0.125	10	—	—
G 130 (noninoculated + 50 kg N ha^{-1})	2790	66	0.285	21	42	19.7
Linseed (50 kg N ha^{-1})	3680	41	0.916	44	89	41.8
Barley (50 kg N ha^{-1})	4960	36	0.809	35	87	40.9
SE	+265	+5	+0.027	+2.5	—	—
CV (%)	19	26	13	23	—	—

1. Calculated with reference to the respective nonfixing control crops.

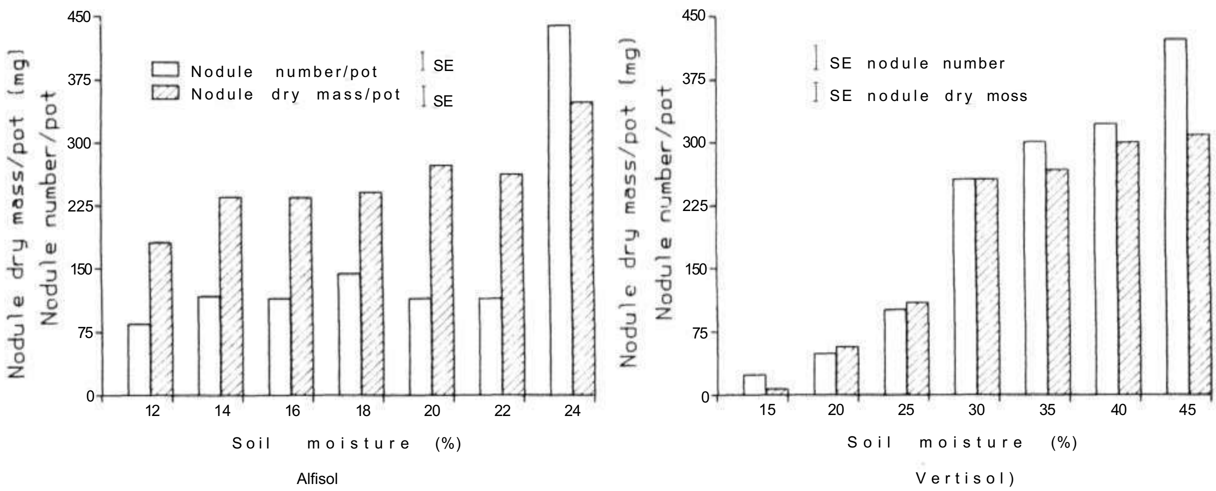

Figure 2. Nodulation of chickpea cultivar K 850 at different soil-moisture levels in an Alfisol (left) and a Vertisol (right), ICRISAT Center, 1984.

necessarily reflect in greater dry-matter production or grain yield. Nodulation and nitrogen-fixing ability of five lines previously known to differ in these characteristics were studied in sand culture using a nitrogen-free nutrient solution. Measurements were made at 15, 30,45, 60, and 75 DAS. Table 6 shows measurements taken at 45 DAS. K 850 had the highest and PCH 119 the lowest nodule mass, with the other lines intermediate. This was reflected in N content and concentration in the whole shoot as well as N concentrations in shoot tip samples. Nodule

Table 6. Nodulation, plant growth, N uptake, and %N in plant tissue of five chickpea cultivars at 45 DAS. Greenhouse pot experiment, ICRISAT Center, 1983/84.

Cultivar	Nodules plant^{-1}	Nodule mass plant^{-1} (mg)	Shoot dry mass plant^{-1} (mg)	N uptake plant^{-1} (mg)	Shoot N content (%)	Growing leaves N content (%)
PCH 119	29	56	830	24	2.56	5.72
Annigeri	47	90	810	28	2.97	6.01
G 130	24	99	830	30	3.20	6.77
P319-1	50	87	700	26	3.39	6.80
K 850	54	136	1040	39	3.56	6.75
SE	±4.6	±9.6	±74	±2.6	±0.147	±0.134

mass was positively correlated with shoot mass (r=0.51, $P<0.01$), acetylene reduction activity (r=0.39, $P<0.01$), total shoot N (r=0.71, $P<0.01$), and N percentage in growing leaves (r=0.55, $P<0.01$). Measuring the N concentration in growing leaves is a potentially useful nondestructive method of estimating N fixation. It could be used in screening segregating populations.

Grain and Food Quality

Cooking Quality

We studied the effect of geographical locations on cooking quality of chickpea. Thirteen genotypes (desi, long-duration) of the International Chickpea Cooperative Trial (ICCT) grown at Hisar and Gwalior and 11 genotypes (desi, short-duration) of a similar trial grown at Derol and ICRISAT Center during the 1982/83 cropping season were examined for their cooking quality. Cooking time, water absorption, and the amount of solids dispersed in the cooking water were determined in dhal samples (decorticated, dry, split cotyledons) of these cultivars. Dhal was prepared by soaking the whole seed in water at 5°C overnight and then manually removing the seed coat. We observed significant differences in the cooking time of these cultivars. Cooking time, and the amounts of solids dispersed showed significant differences due to location in both trials. Location x cultivar interactions were significant ($P<0.05$) for cooking time, water absorption, and the amount of solids dispersed for the short-duration material. The interaction was also significant ($P<0.05$) for cooking time for long-duration material.

Large differences in the seed size and chemical constituents of these genotypes were also observed when they were grown at different locations. Location effects were significant for 100-seed mass, protein, sugar, starch, ash, and fat in the case of long-duration desi genotypes. The average protein content of genotypes was 26.7% from Gwalior and 23.0% from Hisar. The average 100-seed mass was higher at Gwalior than at Hisar, but higher values for fat and starch content were observed in samples from Hisar.

Protein Quality

Results of protein analyses and seed size measurements of 95 lines grown in the last 3 seasons at ICRISAT Center are summarized in Table 7. The average protein content of these lines was 18.4% in 1981, 20.5% in 1982, and 13.0% in 1983, whereas the average 100-seed mass was 14.5 g in 1981, 17.8 g in 1982, and 13.4 g in 1983. The protein content was lowest in the 1983 crop, ranging between 11.0 and 22.3%. Individual data for some of the control entries are shown in Table 8 to demonstrate the magnitude of differences in protein content of these cultivars. There

Table 7. Ranges and means of days to 50% flowering, 100-seed mass (g), and seed protein content (%) of 95 chickpea cultivars, ICRISAT Center, 1981-83.

	Days to 50% flowering			100-seed mass (g)			Seed protein (%)		
	1981	1982	1983	1981	1982	1983	1981	1982	1983
Range	49-88	51-117	56-66	7.9-32.8	11.1-37.7	7.0-28.5	14.9-27.7	17.1-28.2	10.5-22.3
Mean	66.8	74.6	62.2	14.5	17.9	13.4	18.4	20.6	13.0
SD	±8.7	±13.9	±2.5	±5.1	±5.9	±4.4	±1.8	±1.9	±1.4

Table 8. Days to 50% flowering, 100-seed mass (g), and seed protein content (%) of selected chickpea control cultivars included in Table 7.

	Days to 50% flowering			100-seed mass (g)			Seed protein (%)		
Entry	1981	1982	1983	1981	1982	1983	1981	1982	1983
G 130	73	84	65	11.3	13.4	10.5	18.2	19.0	12.8
L 550	64	67	63	19.4	22.7	16.5	16.1	19.0	12.2
GL 651	74	106	64	15.0	17.6	13.5	19.7	23.4	14.9
ANM 772	59	60	59	11.6	14.1	10.8	18.9	20.0	13.5
T 1 A	64	67	61	8.4	11.6	7.2	27.7	28.2	22.3
T 3	74	87	65	15.8	20.9	15.0	16.4	20.8	11.5
Annigeri	53	51	58	19.7	22.9	18.2	16.1	18.4	10.5
H 208	65	85	64	10.2	13.4	13.7	17.6	20.1	12.9
Pant G 114	73	72	63	10.3	12.7	9.0	17.8	18.8	12.7
CPS 1	6!	67	58	14.9	18.0	14.1	17.3	18.0	12.2
Mean	66	74	62	13.7	16.7	12.9	18.6	20.6	13.5

was no significant correlation (r = -0.17) between seed mass and protein content in 1983. Analysis of electrical conductivity in soil samples from the field did not indicate soil salinity. However, one possible explanation for the observed lower protein values might be the late sowing of these cultivars in 1983. This resulted in fewer days to 50% flowering in 1983 (Table 7). Sowing time and rate of maturation effects will be studied more critically in future.

Plant Improvement

Breeding Methodology

We made a half-diallel set of six crosses to initiate fresh studies on the comparison of breeding methods and selection criteria at ICRISAT Center. We screened in a wilt-sick plot and evaluated in normal fields F_2 populations of specific crosses made earlier to combine characteristics of Annigeri (high-yielding and wilt-resistant), K 850 (large seed and wide adaptation), JG 62 (high-yielding and double-podded), ICC 506 EB (*Heliothis* -resistant), and ICCL 83151 (double-podded and wilt-resistant). We selected 160 plants for intercrossing in the F_3 generation. Four F_1s of double cross combinations of single specific crosses were also advanced to the F_2 generation.

We also evaluated 156 F_7 progeny bulks selected from our earlier study of single, three- and four-way crosses; compared 25 lines in replicated yield tests; tested 46 F_2-derived F_5 lines in replicated trials at ICRISAT Center or Gwalior;

and contributed fifteen lines with higher seed yield than the controls (Table 9) to the international chickpea screening nurseries.

Off-Season Nurseries

At ICRISAT Center, we made 88 crosses to obtain additional seeds of crosses attempted in the main season, and multiplied seed of some entries in the international trials and nurseries. We also multiplied 87 F_1s and 718 seed samples from ICARDA, Syria, during the off-season in the postentry quarantine isolation area (PEQIA). Included were 522 F_3 progenies of F_2 plants resistant to ascochyta blight, and 196 ascochyta-resistant lines.

Table 9. Characteristics of some promising chickpea lines in breeding-methodology trials contributed to International Chickpea Screening Nursery (ICSN), ICRISAT Center and Gwalior, 1983/84.

Line/Cultivar	Days to 50% flowering	100-seed mass (g)	Seed yield (kg ha^{-1})
F_2 derived-lines trial			
- desi short duration (ICRISAT Center)			
ICCX 790025-11P-BP	49	17.5	1840
ICCX 790001-10P-BP	54	18.3	1730
Control			
Annigeri	53	19.6	1450
Si-	±1.4	±0.42	±78
Trial Mean	49	18.3	1510
CV (%)	7	6	13
F_2 derived-lines trial			
- desi medium duration (Gwalior)			
ICCX 780083-8G-BG-BG	64	18.4	1860
ICCX 780578-2G-BG-BG	65	17.4	1800
ICCX 780077-20G-BG-BG	67	15.6	1770
ICCX 780073-7G-BG-BG	73	21.5	1700
ICCX 780095-8G-BG-BG	65	15.5	1720
Control			
K 850	80	25.3	1410
SE	±2.6	±0.62	±139
Trial mean	68	17.0	1510
CV (%)	7	6	16
Breeding-methodology trial (ICRISAT Center)			
ICCX 790242-BP-BT-39P-BP	44	20.5	1560
ICCX 790259-BP-BT-38P-BP	51	19.6	1560
ICCX 790248-BP-BT-39P-BP	46	18.3	1500
ICCX 790259-BP-BT-8P-BP	54	17.2	1560
Control			
Annigeri	51	19.0	1330
SE	±1.0	+0.25	+61
Trial mean	50	19.2	1330
CV (%)	6	4	13

At Tapperwaripora in Kashmir, 648 F_1S, 6 F_2s, and 39 lines were grown to advance generations and multiply stocks; most entries produced adequate seed quantities.

Breeding Desi Types

We made more than 300 crosses involving line x tester combinations of adapted, and new cultivars, and diallel sets among the new cultivars. Some were specifically short-duration combinations for regions like peninsular India, while others were long-duration for regions like north India. Line x tester combinations were planned to combine seed yield and wide adaptation in both short- and long-duration types.

We evaluated more than 12000 populations and progenies at ICRISAT Center and Hisar (Table 10). We advanced 405 F_1s, mainly from the line x tester and diallel series at both the locations, to identify high-yielding crosses and to get information on the inheritance of characters. These studies further confirmed that variation in yield and its components is predominantly additive although nonadditive variation is also important.

We evaluated 192 F_2 and 107 F_3 early- to medium-maturing bulks in replicated trials at ICRISAT Center and Gwalior, and 209 F_2 and 56 F_3 long-duration bulks at Hisar and Gwalior. Some of the bulks performed well and significantly outyielded the controls. The higher-yielding F_2 populations have been advanced for further tests and the F_3 populations for plant selection.

At ICRISAT Center we sowed 7315 F_4 to F_8 progenies and at Hisar 3816 F_3 to F_8 progenies. Progenies with adequate seed in the F_5 and more-advanced generations were sown in two sowings. One set of the progenies at ICRISAT Center was grown in the pesticide-free area, and at Hisar the sowings were done on different dates. From various generations we selected a total of 5086 plants at ICRISAT Center and 3728 at Hisar for further progeny tests. We also harvested 537 progeny bulks and the best of these have been contributed to international nurseries, while those remaining will be tested in preliminary yield trials in 1984/85. Nearly 170 germplasm and advanced-generation breeding lines were evaluated in replicated trials at ICRISAT Center, Hisar, and Gwalior. From among the repli-

Table 10. Numbers of desi chickpea populations and progenies grown at ICRISAT Center and Hisar, 1983/84.

	ICRISAT Center		Hisar		Total	
Generation	1st sowing	2nd sowing	1st sowing	2nd sowing	1st sowing	2nd sowing
F_1	213	0	192	0	405	0
F_2	192	0	209	0	401	0
F_3	107	0	212[2]	0	319	0
F_4	393[1]	320	798'	0	1191	320
F_5	2584	1369	1329	1329	3913	2698
F_6	1119	991	650	650	1769	1641
F_7	2333	2225	880	880	3213	3105
F_8	959	865	43	43	1002	908
Total	7900	5770	4313	2902	12213	8672

1. 320 progenies and 73 bulks.
2. 156 progenies and 56 bulks.
3. 756 progenies and 40 bulks.

cated trials conducted in 1983/84, 29 entries will be promoted to international trials and nurseries. ICCV 1 (formerly ICCC 4), which was earlier released for general cultivation in Gujarat State, India, was approved by ICRISAT Plant Material Release Committee for announcement and registration notices.

Breeding Kabuli Types

We obtained six single and 15 backcrosses between high-yielding and large-seeded cultivars. Poor growth prevented selection of any single plants in the F_2 population of earlier crosses. From more than 1400 F_3 and more-advanced bulks and progenies grown, we selected nearly 1600 plants and 80 rows for further tests; the best 19 bulks will be tested in replicated trials next season. We also evaluated 128 lines in replicated trials and selected the best for further tests. ICCC 32 gave excellent performance for the 3rd year in succession in the All India Coordinated Trials and was identified for release in central India. Four lines, ICCV 2 (ICCL 82001), ICCV 3 (ICCL 83006), ICCV 4 (ICCL 83004), and ICCV 5 (ICCL 83009) with acceptable kabuli-type seeds, wilt resistance, and short duration were approved by ICRISAT Plant Material Release Committee for international announcement and registration notices.

Extending Chickpea Adaptation

Early sowing in peninsular India. We could not sow in mid-September at ICRISAT Center as heavy rains continued till the end of that month preventing seedbed preparation. As a result all materials, including F_3 to F_4 progenies, early-sown screening trials, and early- and normal-sown comparisons of previously-identified lines, will be sown next season. However, we did screen 410 F_3 progenies, derived from crosses between wilt-resistant and adapted genotypes, in the wilt-sick plot and selected 684 single plants for further evaluation under early-sown conditions.

Late sowing in northern India. Our efforts at Hisar continued, to identify and develop genotypes suited to late-sown conditions. This is so that chickpea can be grown in rotation with rice, cotton, and other rainy season crops that vacate fields late in the winter season.

A 6x9 line x tester F_1 study in our late sowing, indicated a preponderance of additive genetic variance for days to flowering, seeds pod^{-1} and 100-seed mass, and nonadditive genetic variance for height, branches, pods, and yield plant^{-1}. We grew 901 F_4 to F_6 progenies and selected 537 plants for further evaluation. Superior progenies were bulked and maximum yields of 4020 kg ha^{-1} were recorded in desi and 2520 kg ha^{-1} in kabuli progenies. The highest-yielding 58 desi, and 23 kabuli progenies will be yield tested next year in our late-planted trials. The preliminary and advanced yield trials of germplasm accessions and breeding lines conducted with desi and kabuli genotypes gave encouraging results in spite of the salinity problems at Hisar. The highest yield of 2666 kg ha^{-1} was recorded in NEC 989 compared to 1608 kg ha^{-1} in H 208. Three of our lines, ICCC 14, ICCC 41, and NEC 989, contributed to the late-sown coordinated trials last year performed particularly well in the east and northwest zones of India. They were retained in these zones for further tests. In collaboration with physiologists, 480 germplasm accessions were screened in our late-sowing trials and we identified a few superior entries for inclusion in preliminary yield trials in 1984/85.

Plant Type

Tall, erect habit. Breeding for improved mid-tall, erect, and compact genotypes continued. We made 26 crosses at ICRISAT Center and 67 at Hisar to incorporate disease resistance, double-podded and multiseeded characteristics, and to improve the seed size of tall derivatives.

We did not conduct any F, trial this year but advanced 18 F_1s in nonreplicated plots.

We grew 27 F_2 populations and 780 F_3 to F_8 progeny rows at ICRISAT Center and selected 1423 plants and 48 rows. At Hisar, we selected 1280 single plants and 10 rows from 27 F_2 populations and 2237 progenies. We conducted two preliminary yield trials of the promising advanced tall lines, one each at ICRISAT Center and Hisar. Because of the salinity problems at Hisar, the collected data could not be analyzed. At ICRISAT Center, however, the trial was good and a number of tall entries exceeded the yield of Annigeri as well as the best tall control; the top five are presented in Table 11. A multilocational trial of promising tall lines was sent to ten locations in India. None of the tall lines gave higher overall yield than the common control, K 850, yet at individual locations some of the entries out-yielded the common and local controls. We think the yield potential of tall lines can be further improved by improving their sink size through adding double-podded and multiseeded characteristics and increasing seed size.

Double-podded and multiseeded types. Selection to combine double-podded and multiseeded characteristics with high yield and disease resistance continued. We made 68 three-way crosses involving multiseeded, double-podded and wilt-resistant, high-yielding, and ascochyta blight-resistant genotypes.

Table 11. Plant height (cm) and seed yield (kg ha^{-1}) of five highest-yielding, tall chickpea genotypes compared with Annigeri and a tall control, ICRISAT Center, 1983/84.

Line/Cultivar	Plant height (cm)	Seed yield (kg ha^{-1})
ICCX 750016-42-1P-1P-1P-1P-BP	41.6	1410
ICCX 770909-BH-5H-1P-BP	37.6	1350
ICCX 761459-69H-1P-BP-BP	54.7	1180
ICCX 750016-33-1P-1P-1P-1P-BP	47.1	1160
ICCX 761293-10H-1H-2H-2P-BP	49.3	1130
Controls		
Annigeri	22.6	880
750073-4-1P-1P-BP	42.4	810
SE	±1.25	±66
Trial mean	40.1	996
CV (%)	5	11

Table 12. Number of seeds pod^{-1} in early-developed multiseeded chickpea lines grown at ICRISAT Center, 1983/84.

Multiseeded line	Mean	SE
2	1.79	±0.041
13	1.84	±0.042
24	1.70	±0.079
28	1.70	±0.070
46	1.84	±0.138
49	1.63	±0.067
59	1.76	±0.048
60	1.85	±0.060
62	1.71	±0.059
66	2.03	±0.154
Control		
Annigeri	1.18	±0.031

We grew 29 F_2 populations in the wilt-sick plot, 12 F_2 populations, and 4212 F_3 to F_6 progenies in normal fields at ICRISAT Center; and 12 F_2 populations in the wilt-sick plot, 8 F_2 populations, and 3205 F_3 to F_6 progenies in normal fields at Hisar. All progenies were evaluated for their multiseeded characteristics and seed yield, and we selected more than 4300 single plants and 54 rows from those combining multiseeded or double-podded characteristics, and having higher seed yields than the moving averages of control cultivars. Of these, 16 lines were contributed to ISNs.

At ICRISAT Center, 72 lines derived from multiseeded pods in the previous years were compared with Annigeri for their number of seeds pod^{-1}. Ten uniform lines, which produced considerably more seeds pod^{-1} (Table 12) than Annigeri, were bulked for further studies to be conducted in collaboration with the physiologists.

Cooperative Activities

In 1983/84, there was a phenomenal increase in the number of international trials distributed to cooperators (Fig. 3). As in 1983, to meet specific situations, material was grouped as short-,

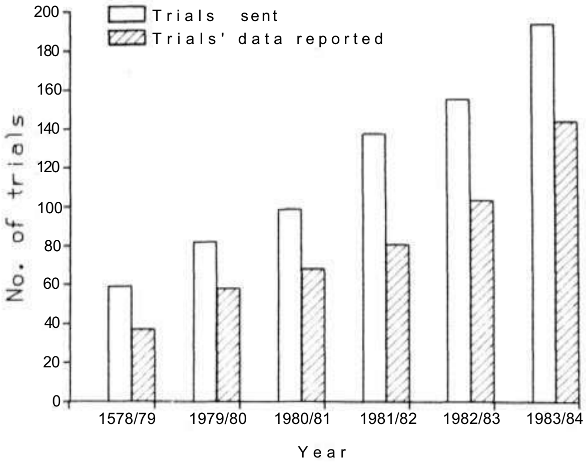

Figure 3. Growth in numbers of International Chickpea Trials and Nurseries from 1978/79 to 1983/84.

medium-, and long-duration. We continued to incorporate ascochyta blight resistance in long-duration genotypes for the western sector, and gray mold resistance in short-duration genotypes for the eastern sector of the Indian subcontinent. Unlike 1983, there was no ascochyta blight this season, hence no fear of spreading the disease through seed. We therefore distributed F_2 and F_3 trials of the long-duration category also. We additionally constituted a tall type multilocational trial that was distributed to nine northern Indian locations and also conducted at ICRISAT Center.

International Trials and Nurseries

We distributed 195 sets of 14 different international trials and nurseries of breeding material to 52 cooperators in 15 countries (Table 13). As in previous seasons, we noted that few F_2 and F_3 segregating bulks gave significantly higher yields than the local and common controls at individual locations, although some were significantly better overall. In general, cooperators were satisfied with the amount of variability in the segregating bulks.

In the International Chickpea Screening Nurseries (ICSNs), many entries performed better than the controls at individual locations. However, the best yields overall were from ICC 11172

Table 13. International chickpea trials and nurseries distributed by ICRISAT, 1983/84.

Country	F_2MLTDS	F_2MLTDM	F_2MLTDL	F_3MLTDS	F_3MLTDM	F_3MLTDL	ICSNDS	ICSNDM	ICSNDL	ICCTDS	ICCTDL	ICAT	PTMLT	Total
Bangladesh	1			1			2			3				7
Belize							1	1		1				3
Burma							1			1				2
Canada								1	1		1			3
Ethiopia	1	1					1	1		1				5
India	8	8	13	12	8	11	14	12	10	16	11	12	9	144
Lesotho												2		2
Mexico											1			1
Nepal								1	1		1			3
Nigeria										1				1
Pakistan		1	3		3	3	3	2	4		3			19
Philippines							1			1				2
Sudan										1				1
Tanzania										1				1
Thailand										1				1
Total	10	10	16	13	11	14	23	18	16	27	17	14	9	195

MLT = Multilocational Trial; DS = Desi Short-duration; DM = Desi Medium-duration; DL = Desi Long-duration; ICSN = International Chickpea Screening Nursery; ICCT = International Chickpea Cooperative Trial; ICAT = International Chickpea Adaptation Trial; PT = Plant Type.

in short-duration, ICCL 82119 in medium-duration, and ICCL 82435 in long-duration nurseries.

In the International Chickpea Cooperative Trial Desi Short-Duration (ICCTDS), ICCL 81215 followed by ICCL 82127 produced the highest seed yields and both were entered in All India Coordinated Trials. ICCL 80107 gave the second-highest yields in the International Chickpea Cooperative Trial Desi Long-Duration (ICCTDL) and was also entered in coordinated trials.

In collaboration with ICARDA we continued distributing the chickpea adaptation trial for the 3rd year. Fourteen sets were supplied by ICRISAT and more than 60 by ICARDA. Data have been assembled for many variables for the 3 seasons and have been entered into the computer for analysis and assessment.

Distribution of Breeders' Material

We supplied seeds of 5464 samples of segregating populations and other breeding materials to cooperators in India and other countries in response to specific requests.

Cooperation with All India Coordinated Pulses Improvement Project (AICPIP)

As in the past, we again screened germplasm accessions, entries from AICPIP chickpea varietal trials, and breeding materials from AICPIP scientists for resistance to fusarium wilt and other soilborne diseases, ascochyta blight, and botrytis gray mold, and communicated the results to them.

The national uniform testing for chickpea wilt and root rots wasjointly organized by ICRISAT and AICPIP through the 3rd ICRISAT/ICAR Uniform Chickpea Wilt/Root Rots Nursery (IIUCWRRN). The trial consisting of 60 entries (all contributed by ICRISAT) was conducted at 11 locations in India. The results are reported in Pulse Pathology Progress Report No. 41.

Out of the 18 entries in AICPIP trials in various zones, ICCC 22 ranked 4th and ICCC 37 2nd in the Gram Coordinated Varietal Trial-South Zone (GCVT-SZ) for seed yield; ICCC 40 finished 2nd in the Gram Initial Evaluation Trial-Central Zone (GIET-CZ); and ICCC 36 3rd, and ICCC 39 4th in the Gram Initial Evaluation Trial-South Zone (GIET-SZ). Besides these, desi entries promoted or retained in different trials were ICCC 27, 28, 29, 30, 35, 38, and P 1329. Among kabulis, ICCC 32 performed better than the control, L 550 for 3 consecutive seasons. It was identified for release in the central zone of India and the seed has been sent for minikit trials. ICCC 25, 33, and 34 will be further tested in kabuli trials next season. Three entries, ICCC 14, 41, and NEC 989, performed well in the GIET late-sown trials and were retained for further tests. Five new lines, ICCC42,43,44,45, and 46 were contributed to coordinated trials for testing in the 1984/85 season. In addition, several entries contributed to AICPIP trials by our cooperators are selections from 1CRISAT materials. Following the release of ICCC 4 (ICCV 1) in Gujarat, many seed requests were received and met. We supplied 130 kg of breeders' seed of ICCC 4 to Gujarat State to supplement their multiplication program.

Cooperation with ICARDA

ICRISAT has stationed two chickpea scientists at ICARDA to work on kabuli chickpeas for spring and winter sowing in the Mediterranean region of west Asia, northern Africa, and southern Europe, and in the Americas. Most of the work reported here was carried out by them, in collaboration with national programs and with chickpea scientists at ICRISAT and ICARDA.

Plant Improvement

Ascochyta blight resistance is very important in the Mediterranean region and therefore efforts have been directed towards the development of only ascochyta blight-resistant material at Tel Hadya. Lines that show high susceptibility to cold, heat, iron deficiency, *Orobanche* sp, and

Ascochyta blight-resistant chickpea line (left) growing alongside susceptible line (right) in epidemiological study, Syria, 1984.

leaf miner *(Liriomyza cicerina)* are also rejected. Advanced segregating populations are grown during winter and spring. The genetic stocks developed are evaluated for grain yield during both winter and spring at three sites in Syria and one in Lebanon that differ in agroclimatic conditions and altitude. Lines that perform well are made available to the national programs.

Germplasm evaluation. A total of 1797 kabuli chickpea germplasm accessions grown during winter were evaluated for days to flowering and maturity, plant height, pods plant^{-1}, pod dehiscence, biological yield, seed yield, harvest index, resistance to leaf miner, and susceptibility to iron deficiency. These lines are also being evaluated for their protein content and cooking time.

***Orobanche* resistance.** The parasitic weed *Orobanche* sp is not a problem in spring, but could become a problem in the winter crop. As a routine, newly-developed lines are screened against *Orobanche* and susceptible lines are rejected. During 1983/84, we screened 193 lines and found 170 of them tolerant.

We have rescreened 500 promising germplasm lines and identified 11 resistant lines. These are ILC 83, 132, 134, 71, 201, 202, 299, 349, 1346, 2500, and 3274.

Ascochyta blight-resistant genetic stocks. The germplasm lines with resistance to ascochyta blight have an intermediate type of seed (neither desi nor kabuli) and are late-maturing. Attempts were made to transfer the gene for resistance into a better genetic background. Eight lines having kabuli-type seed, early flowering, good seed size, and blight resistance have now been developed, and used as resistance sources in the hybridization program.

International nurseries and yield trials. The international testing program was initiated during 1977/78. In the first year, 34 sets of 2 nurseries were sent to 15 national programs; by 1984 the number of trials we sent out had substantially increased. Three hundred and seventy sets of 10 nurseries were furnished to 40 national programs, an eleven-fold increase over 1977/78.

Ten national programs, Cyprus, Egypt, Jordan, Lebanon, Morocco, Oman, Pakistan, Spain, Syria, and Tunisia have selected genotypes from the international nurseries for on-farm trials or multilocational testing (Table 14).

Table 14. Chickpea lines supplied by ICARDA and included in multilocational or on-farm trials by national programs, 1983/84.

Country	Cultivar
Cyprus	ILC 3279
Egypt	ILC 195, 482, 484
Jordan	ILC 484, 202
Lebanon	ILC 482
Morocco	ILC 195,482,484
Oman	ILC 3279, 80-5
Pakistan	FLIP 82-8C, 82-52C, 82-69C, 82-5C, 82-43C
Spain	ILC 72, 200
Syria	ILC 72, 195, 202, 3279, 620, 629, FLIP 82-64C, FLIP 82-236C
Tunisia	ILC 482

ILC 3279 released for winter sowing in Cyprus. Chickpea cultivar ILC 3279, a selection made from an introduction from the USSR, has produced consistently high yields in winter sowings in Cyprus. This cultivar is highly resistant to ascochyta blight and tolerant to cold. It is tall and thus can easily be harvested mechanically. The national program of Cyprus has released it for winter sowing.

Crossing program. During the 1983/84 season, we made 401 crosses. Of these, 275 crosses were made to develop genetic stocks and cultivars, 90 crosses for the national programs of Egypt, Italy, Jordan, Morocco, and Tunisia, and 36 crosses for genetic studies on resistance to ascochyta blight, fusarium wilt, and leaf miner. The majority of the crosses made this year were between lines bred at ICARDA and germplasm accessions, a significant departure from earlier years when crosses were almost exclusively among germplasm accessions. The F,s were grown in the off-season in Sarghaya under 24 h of daylight to advance the generation.

Segregating populations. The material from F_2 to F_4 generations was grown during the winter at Tel Hadya. The F_5 to F_7 progeny rows were grown during both winter and spring at Tel Hadya, Syria (Table 15). The selection criteria

Table 15. Number of chickpea segregating lines grown, single plants selected, and progenies bulked at Tel Hadya, Syria, 1983/84.

Generation	Segregating lines grown	Single plants selected	Progenies bulked
F_2 Population	242	5112	0
F_3 Progeny	4927	2345	0
F_4 Progeny	3164	1741	28
F_5 Progeny	1998[1]	517	97
F_6 Progeny	1860[1]	520	44
F_7 Progeny	966[1]	0	21

1. Includes some progenies grown during both winter and spring.

for material grown in F_2 through F_4 included rogueing out plants susceptible to cold and iron deficiency, and selecting plants with resistance to ascochyta blight, acceptable seed quality, short duration, and tall stature. Yield and adaptation to winter and spring sowing were the main criteria for selection in the F_5 to F_7 generations.

Spring and winter yield trials. A total of 140 newly-developed lines were evaluated during the winter and spring seasons for seed yield at Tel Hadya and Terbol; in spring only 14 lines exceeded the yield of the local control at Tel Hadya and four lines exceeded the control at Terbol (Table 16). In the winter planting, as many as 76 lines at Tel Hadya and 30 lines at Terbol exceeded the control yield, but only eight lines at Tel Hadya yielded significantly more than the control. In contrast to the highest yield of 331 kg ha^{-1} in the spring-sown trials at Tel Hadya, the top yield in the winter sown trials was 3070 kg ha^{-1}, an eight-fold increase. At Terbol some entries produced more than 3500 kg ha^{-1}.

Large-seeded tall chickpea. We have bred 20 lines that combine large seed, high yield, and blight resistance; the ten best are shown in Table 17. Irrespective of their yield performance, the lines combining large seed size and ascochyta blight resistance could go a long way toward introducing chickpea cultivation during winter, and thus the prospect of increasing chickpea production has brightened, even in such Mediterranean countries as Spain.

Newly-developed, short-duration kabuli chickpea cultivar that is resistant to ascochyta blight, cold tolerant, and large-seeded. This cultivar is now in advanced yield trials in Syria.

A number of lines with high yield, blight resistance, kabuli-type large seed, and tall stature have been developed for the first time. The plant height and 100-seed mass of a few lines bulked last season are shown in Table 18.

Table 16. Mean yield (kg ha^{-1}) performance of 140 newly-developed chickpea lines in Syria and Lebanon, winter and spring, 1983/84.

Location	Entries exceeding control	Mean yield (kg ha^{-1})	SE	Range for highest-yielding lines in trials (kg ha^{-1})
Tel Hadya, Syria				
Winter	76	1710	±386	2360-3070
Spring	14	120	+89	150- 331
Terbol, Lebanon				
Winter	30	2150	±532	1880-3600
Spring	4	1400	+325	1610-2000

Table 17. 100-seed mass (g) of some newly-bulked, large-seeded, and blight-resistant chickpea lines, Tel Hadya, Syria, 1983/84.

Pedigree	100-seed mass (g)
ILC 112 x ILC 191	50.1
ILC 191 x ILC 262	48.6
ILC 470 x ILC 2956	45.6
ILC 3279 x ILC 3355	46.5
Control	
ILC 464	46.0
ILC 202 x ILC 3355	43.8
ILC 3279 x ILC 3355	43.9
ILC 72 x ILC 1922	43.0
ILC 2956 x ILC 3279	41.7
ILC 202 x ILC 256	42.4
ILC 112 x ILC 191	41.6
SE	±0.71
Mean	43.6

Table 18. Plant height (cm) and 100-seed mass (g) of some newly-bulked, tall, and blight-resistant chickpea lines, Tel Hadya, Syria, 1983/84.

Pedigree	Plant height (cm)	100-seed mass (g)
ILC 610 x ILC 72	65	32.9
ILC 1920 x ILC 2956	65	34.2
ILC 1920 x ILC 2956	70	34.7
ILC 1920 x ILC 2956	60	32.2
ILC 72 x ILC 482	60	31.6
ILC 72 x ILC 482	65	32.2
ILC 72 x ILC 484	60	31.1
ILC 72 x ILC 484	70	34.7
ILC 72 x ILC 484	65	31.2
ILC 72 x ILC 73	70	38.0
Control		
ILC 3279	67	27.6
SE	+0.78	+0.80
Mean	62.7	30.5

On-farm trials. On-farm trials were continued by the Syrian Ministry of Agriculture, and ICARDA. These trials were conducted at 16 locations with eight entries in winter, six in spring, and three entries common to both seasons. ILC 482 was still the highest-yielding cultivar during winter sowing and the Syrian local landrace maintained its yield superiority in the spring sowing (Table 19). Three cultivars, ILC 72, 202, and 3279, were taller and thus more suited for mechanical harvesting. Based on 3 years' data, ILC 3279 was the 2nd highest-yielder in winter, and because of its high blight resistance and tall stature, is under consideration for release in Syria.

Diseases and their Control

Disease situation in West Asia and northern Africa. Ascochyta blight (*Ascochyta rabiei*), that caused serious losses in the region during the past 3-4 years, was not such a problem this season because of the dry weather. Ascochyta blight and chickpea production are both dependent on the weather. When it is dry, there is no ascochyta blight, but the crop harvest is poor. When the weather is wet, there is scope for a good harvest, but the crop is more susceptible to blight. Thus blight control is essential to increase and stabilize chickpea production in the region.

Ascochyta blight was observed this year in the southern part of Tahrir province, in Egypt, where chickpea is being cultivated under sprinkler irrigation on newly-reclaimed desert lands. This is the first report of the occurrence of ascochyta blight in Egypt and has now been documented by Egyptian workers.

Isolations from wilted plants from Tunisia and Syria revealed the presence of *Verticillium* sp in addition to *Fusarium oxysporum.*

A survey of plant parasitic nematodes of leguminous crops in Syria showed that chickpea is a host to 12 nematode genera. Of these *Meterodera* sp were extracted from 24%, *Meloidogyne artiellia* from 12%, and *Pratylenchus thornei* from 60% of the collected samples, and appeared to be the most damaging nematodes.

International Ascochyta Blight Nursery. Forty sets of 70 ascochyta blight-resistant lines were

Table 19. Mean seed yield (kg ha^{-1}) of chickpea lines tested in on-farm trials at 16 locations, Syria, winter and spring, 1983/84.

Entry	Winter Yield (kg ha^{-1})	Winter Rank	Spring Yield (kg ha^{-1})	Spring Rank
ILC 72	1160	5	0	0
ILC 195	1180	4	0	0
ILC 202	1130	7	0	0
ILC 484	1410	2	0	0
ILC 3279	1090	8	0	0
FLIP 82-64	1150	6	700	A
FLIP 82-236	1280	3	810	5
Control				
ILC 482	1450	1	850	3
ILC 620	ND'	ND[1]	820	4
ILC 629	ND	ND	870	*2*
Control				
Syrian local	ND	ND	920	1
SE	+135		+26	
CV (%)	21		17	

1. ND = Not determined.

supplied to 18 national programs mainly in west Asia and northern Africa through the Chickpea International Ascochyta Blight Nursery 84 (CIABN). The entries included 21 desi and 22 kabuli germplasm accessions, and 27 kabuli lines developed through hybridization.

New sources of resistance to ascochyta blight. In advanced screening of germplasm accessions for resistance to blight, for a 2nd year 9 new lines were found to be resistant at two ICARDA locations in Syria (Tel Hadya and Lattakia)and one in Lebanon (Terbol). These lines were ILC 3803 (kabuli), and ICC 4181, 4475, 8486, 9189, 9501, 9514, 12023, CAM 72, and 94 (all desi).

Sources of resistance to a virulent race of *A. rabiei*. We screened a total of 5000 germplasm accessions, comprising desi and kabuli types for resistance to the newly-identified race 6 of *A. rabiei.* Most of the lines resistant to race 3 showed susceptibility to race 6. In repeated screenings, five lines, ICC 6988 (desi), and ILC 187, 202, 3346, and Pch 128 (all kabuli), showed resistance or tolerance to the new race.

Durable blight resistance. In an attempt to identify lines with durable resistance to blight, lines were screened against different races of *A. rabiei,* under different regimes of relative humidity, and inoculum concentrations. The search for durable resistance was made amongst the lines identified as resistant to race 3, and those found resistant in the multiple locations of the International Blight Resistance Testing Program.

Of 30 such lines screened against 6 races, five lines (ILC 72, 187, 2506, 3856, and 3864) showed low disease severity compared to the susceptible control ILC 1929. (Table 20). These lines also showed low *A. rabiei* sporulation when measured one month after inoculation in the seedling stage.

The reaction of 10 genotypes to race 3 was studied at different 100% relative humidity peri-

Table 20. Chickpea lines with low disease severity and fungus sporulation against six races of *Ascochyta rabiei*, Tel Hadya, Syria, 1983/84.

Genotype	Blight severity[1]					
	Race 1	Race 2	Race 3	Race 4	Race 5	Race 6
ILC 72	3	3.5	3	3	3	4
ILC 187	3	3.5	3	3	3.5	3
ILC 2506	3	3	4	3	3	3
ILC 3856	2,5	3	4	4	3	3.5
ILC 3864	2.5	3	4	4	3	3
Control						
ILC 1929[2]	7	9	8	9	9	8

1. Based on a 1-9 scale, where 1 = no disease, 9 = complete death of plants.
2. Susceptible.

ods (0-30 days) and spore concentrations (0.05-7.5 million mL^{-1}) to identify lines resistant under different conditions. The increase in 100% relative humidity from 2 to 30 days and inoculum concentration from 0.1 -7.5 million mL^{-1} did not significantly change the reaction of ICC 3996 (desi), ILC 72, 187, 200, and 3279 (all kabuli).

Blight severity and yield loss relationship. We investigated the relationship between ascochyta blight severity (on a 1-9 scale) and yield loss in a field trial with 16 kabuli and 4 desi lines. The trial was sown in the winter season at Tel Hadya in a split-plot design with genotypes as subplots and protected and diseased treatments as main plots. Our results indicated that the loss in yield of kabuli lines rated as resistant (1-3) or moderately resistant (4) is minimal but in desi lines it is substantial (Table 21).

In another trial we estimated the yield loss of 12 kabuli and 6 desi lines rated as resistant or moderately-resistant. In kabuli lines rated as resistant or moderately-resistant, there was no loss in yield; in fact a slight increase was observed. In desi lines rated as moderately-resistant, the yield loss was substantial (Table 22).

Table 21. Ascochyta blight severity and yield loss relationship in kabuli and desi chickpeas, Tel Hadya, Syria, winter 1983/84.

Blight severity category[1]	Plant type	Entries	Yield (kg ha-')		Yield loss (%)
			Protected	Diseased	
Resistant	Kabuli	4	1440 ±114	1400 ±114	2.8
	Desi	1	2250 +228	1240 +228	44.9
Moderately resistant	Kabuli	6	2160 +93	2030 +93	6.2
	Desi	2	2200 +161	1180 +161	46.4
Tolerant	Kabuli	2	2540 +161	2040 +161	19.5
	Desi	1	2640 +228	1360 +228	48.6
Susceptible	Kabuli	4	2520 +114	0	100.0
CV (%)				15	

1. Categories based on a 1-9 scale, where 1-3 = resistant, 4 = moderately resistant, 5 = tolerant, and 6-9 = susceptible.

Table 22. Estimation of yield loss (%) due to blight in resistant and moderately-resistant kabuli and desi chickpea lines, Tel Hadya, Syria, winter 1983/84.

Blight severity category	Plant type	Entries	Yield (kg ha^{-1}) Protected	Yield (kg ha^{-1}) Diseased	Yield decrease or increase (%)
Resistant	Kabuli	5	1940	2050	+ 5.6
	Desi	3	2290	2070	- 9.6
Moderately resistant	Kabuli	7	1910	1990	+ 4.0
	Desi	3	2570	1500	- 41.4
Susceptible	Kabuli	1	2790	0[1]	-100.0
SE for comparing:					
main plot at same subplot level			+254		
subplot at same mainplot level			+556		
CV (%)			15.1		

1. Not included in calculation of SE.

Epidemiology. We continued for the 2nd year a field experiment designed to study development of ascochyta blight in relation to temperature and relative humidity. The results of the 1984 experiment were similar to those obtained in 1983. Temperature and relative humidity, both had an important influence on blight development. Blight started building up rapidly when the daily mean temperature rose above 10° C and relative humidity remained above 60% (Fig. 4). These conditions prevailed in the first week of February, 1984.

Integrated control. We have attempted to develop integrated control of ascochyta blight. We used fungicidal application in conjunction with a disease-tolerant cultivar. Earlier tests had indicated that fungicidal sprays used on a susceptible cultivar are uneconomical; however, they are economical if the cultivar is tolerant.

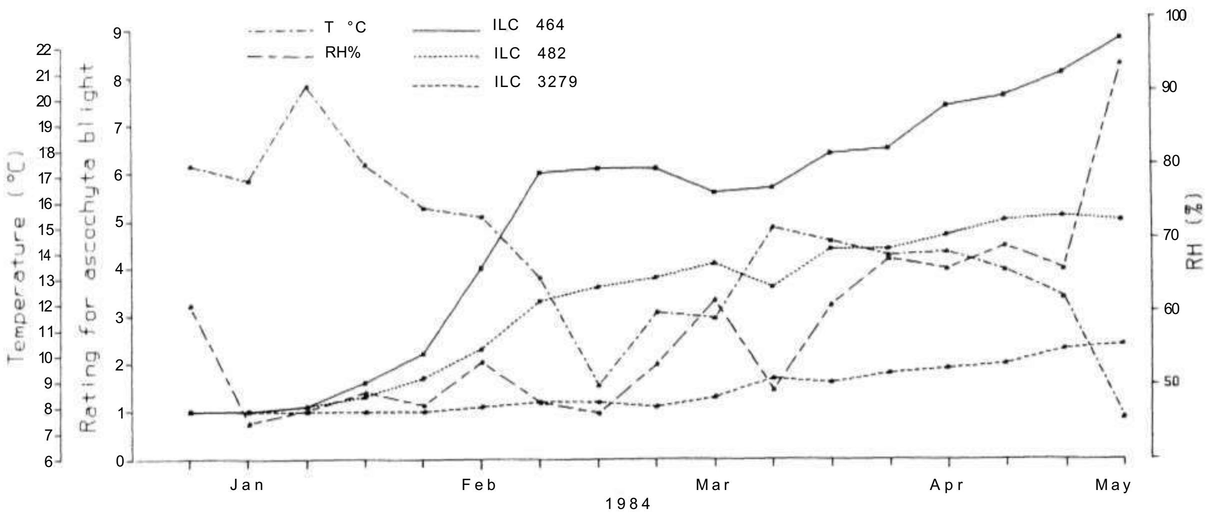

Figure 4. Ascochyta blight severity rating (1-9 scale) for three chickpea cultivars in relation to temperature (° C) and relative humidity (RH%), blight epidemiology trial, Tel Hadya, Syria. 1983/84.

The results of a field trial conducted for the 3rd season using tolerant cultivar, ILC 482 with foliar sprays of chlorothalonil showed that two sprays, one at the seedling stage and the other either at the early- or late-podding stages, prevented any yield loss. Spraying at seedling and early-podding stages significantly reduced the extent of pod infection (Table 23). Spraying at the early-podding stage also reduced the extent of seed infection. Spraying at seedling and podding stages alone did not increase yield. In the earlier experiments a response was obtained to spraying at early-podding stage alone. This season the disease severity in the vegetative stage was higher and pod infection was lower than in previous years. The higher pod infection with spraying at the seedling stage, and seedling and late-podding stages seemed to be due to early flowering of the crop in those treatments that coincided with favourable conditions for blight infection.

Effect of planting method and fungicidal seed-dressing on plant stand and yield. A field experiment to study the effect of ridge or flat planting and fungicidal seed-dressing on plant stand and yield of chickpeas was conducted in the spring season at Terbol in Lebanon for the 3rd year. The results of the experiment confirmed the earlier findings that ridge planting improves the stand and yield of spring-sown chickpeas and also fungicidal seed-dressings, such as captan and metalaxyl (Ridomil ®) significantly increase stands and yields (Table 24).

Host range of cyst and lesion nematodes. A total of 46 crop species common to the Mediterranean region were tested against cyst *(Heterodera* sp), and lesion (*Pratylenchus thornei)* nematodes to determine their host range. We tested for the cyst nematode in artificially-infested soil in pots in a plastic house, and for lesion nematode in a naturally-infested field plot. Cyst nematode infestation was observed only on chickpea, lentil, *Lathyrus,* peas, soybean, lupines, *Phaseolus* beans, medics, and vetch indicating that its host range is confined to legumes. However, it did not infest faba bean *(Vicia faba).* The host range of the lesion nematode was much wider and it infested legumes, cereals, and some cruciferous crops. However, it did not infest *Lathyrus*.

Screening for resistance. In a preliminary greenhouse evaluation, we screened 290 genotypes of chickpea using soil in pots artificially

Table 23. Effect of chlorothalonil foliar sprays on ascochyta blight severity and yield (kg ha^{-1}) of the blight-tolerant chickpea cultivar ILC 482, Tel Hadya, Syria, winter 1983/84.

Number and time of spray	Blight severity[1] on vegetative parts	Yield (kg ha^{-1})	Days to 50% flowering
No sprays	5.3	1570	127
2 sprays SS[2] + EPS[2]	3	2600	124
2 sprays SS + LPS[2]	4.3	2260	125
Complete protection	3	2330	127
SE	±0.3	±195	±0.6
CV (%)	13.2	16.9	0.8

1. Based on a 1-9 scale, where 1 = no disease, 9 = plants completely killed.
2. SS = Seedling stage, EPS = Early podding stage, LPS = Late podding stage.

Table 24. Effect of planting method and fungicidal seed-dressing on plant stand and yield (kg ha^{-1}) of chickpea at Terbol, Lebanon, spring 1984.

Fungicidal treatment	Plant stand (200)		Yield (kg ha^{-1})	
	Flat	Ridge	Flat	Ridge
Ridomil®	133	148	2380	2650
captan	140	142	2320	2610
Control	83	130	1680	2550
SE for comparing:				
methods at same treatment level	+13.2		+219	
treatments at same method	+13.0		+211	
CV (%)	13.1		12.3	

infested with cyst nematode (*Heterodera rosii).* These genotypes mainly consisted of ascochyta blight-resistant kabuli and desi germplasm accessions and newly-developed kabuli lines. Twenty-seven lines were rated 4 and less on a 0-10 scale, where 0=no damage and 10= completely killed.

One hundred ascochyta blight-resistant lines were evaluated for resistance in a field infested with lesion nematodes. The nematode population in the plot before sowing ranged from 101 to 969/500cc of soil. Not much variation in the extent of damage was observed between genotypes.

Pakistan

With financial assistance from the Asian Development Bank (ADB) and in cooperation with the National Agricultural Research Center (NARC), Islamabad, we initiated work on the development of high-yielding chickpeas with a high level of resistance to ascochyta blight.

Ten yield trials were sown in November at the NARC, of which five were Preliminary Yield Trials (PYT), two Advanced Generation Yield Trials, two Major Yield Trials, and one a National Uniform Yield Trial. These trials included desi and kabuli types of about 15 selections, each of which was sown in 4-6 rows 1 m long, replicated four times, in randomized complete block designs. The National Uniform Yield Trial was sown at 20 locations throughout Pakistan using 14 selections, made by various research centers in Pakistan. Potentially-promising materials were sent to various research centers in the provinces of Pakistan for evaluation under local conditions. The material included segregating populations as well as selections/varieties produced at NARC, ICRISAT and/or ICARDA. Apart from these, varying numbers of F_1, F_2, F_3, and F_4 populations from NARC, ICRISAT, and ICARDA were sown in unreplicated single rows for further selection.

Single rows of over 2000 germplasm accessions were sown in November at NARC for screening against ascochyta blight. Single rows of about 5000 germplasm accessions were also sown at NARC for screening against *Heliothis armigera.*

Workshops, Conferences, and Seminars

Chickpea Scientists' Meet

ICRISAT hosted the Annual Chickpea Scientists' Meet at ICRISAT Center, 15-17 February. There were 36 participants from six countries: 1 each from Bangladesh, Ethiopia, and Nepal, 2 each from Pakistan and Burma, and 29 from India. Three members of the ICRISAT External Program Review Panel also met with the visiting scientists.

ICRISAT chickpea breeders presented their work on different aspects of breeding. Participants then made a field tour of the chickpea experiments conducted by the Pulses Improvement and Farming Systems Programs and the Genetic Resources Unit.

The scientists spent three half-day sessions in the chickpea fields and made 1172 selections. Seed of the entries selected for sowing in the coming season is being prepared for distribution.

In a discussion session on 'Relationships of disciplines to breeding', ICRISAT scientists emphasized the importance and contributions of a range of disciplines to the breeding program.

Consultants Workshop on Adaptation of Chickpea and Pigeonpea for Tolerance to Abiotic Stresses

This workshop was held at ICRISAT Center, 19-21 December to review the current knowledge on chickpea and pigeonpea tolerance to such abiotic stresses as water (drought and waterlogging), salinity, pH, and others, and to formulate a program of future work. Five consultants from four countries and ICRISAT staff participated.

The meeting found a need for a proper assessment of the magnitude, and timing of occurrence of different types of stresses, and the relative losses in yield that they induce in these two crops in different regions. Discussions on drought were around three major points: climatological quantification, crop management strategies in drought environments, and crop improvement for drought tolerance. Waterlogging, salinity, and low pH problems were discussed in depth, in terms of the relative merits of amelioration, or crop improvement strategies to cope with the problem.

It was apparent from the deliberations that very limited information is available on the response to drought and other stresses in both the crops, and on drought in pigeonpea in particular. Proceedings are in preparation and will be available from Information Services, ICRISAT.

Looking Ahead

We will start work on new levels in environments with constraints of soil and climate. Genotypes adapted to high inputs of fertilizers and water will be identified. We will intensify our work on tolerance to drought, salinity, and plant stand establishment under limited seedbed moisture and will investigate in detail interactions between soil moisture and nutrient uptake.

We will initiate studies on population changes of chickpea rhizobia in soil profiles over time, and on the effect of depth of sowing on nodulation patterns. The residual effects of chickpea in supplying nitrogen to succeeding crops will also be studied. We will make an assessment of the potential for mycorrhizal inoculation of chickpea.

Work on the physiologic races of *Fusarium oxysporum* f.sp *ciceri* will be intensified. Breeding for multiple disease resistance will receive greater attention.

Progenies of crosses intended to combine resistances to both *Heliothis armigera* and fusarium wilt are now being screened. Selections should be available for multilocational testing within the next 3 years.

Emphasis will continue on breeding for improved and stable yield potential by incorporating genetic resistance to various biotic and abiotic stress factors. Genotypes that combine multiple disease and insect resistance should soon be available for multilocational testing.

The work to identify and breed genotypes adapted to nontraditional situations, such as early sowing in peninsular India, and late sowing and high-input conditions in northern India, will continue. It is intended to continue intercrossing in selected mid-tall, multiseeded, and double-podded lines and to incorporate these characteristics into improved backgrounds in order to improve existing yield levels.

The Asian Regional Grain Legume Program and the ADB-supported chickpea improvement project in Pakistan will help strengthen chickpea research in Bangladesh, Burma, Nepal, and Pakistan, and possibly in a few Southeast Asian countries.

The emphasis of our breeding program at ICARDA will continue to be on developing lines for winter and spring sowing with high yield, large kabuli seed type, tall stature, different maturities, and blight resistance. In addition to blight resistance, development of lines with tolerance to *Orobanche* sp, cold, wilt, leaf miner, and nematodes is necessary.

Publications

Institute Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Pulses Improvement Program. 1984. International Chickpea Newsletter nos. 10 and 11 (Beniwal, S.P.S., ed.). Patancheru, A.P. 502 324, India: ICRISAT. 35 and 61 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 98 pp,

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Chickpea Cultivar ICCV 1. Plant Material Description no.9. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp.

Rupela, O.P., Dart, P.J., Toomsan, B., Singh, D.V., Subramaniam, D., and Sharma, B.K. 1984. Facility for growing plants in test tubes at ICRISAT. Information Bulletin no. 18. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 8 pp.

Thompson, J.A. 1984. Production and quality control of carrier-based legume inoculants. Information Bulletin no. 17. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 37 pp.

Journal Articles

Reddy, M.V., and Singh, K.B. 1984. Evaluation of a world collection of chickpea germplasm accessions for resistance to ascochyta blight. Plant Disease 68:900-901.

Singh, K.B., Reddy, M.V., and Nene, Y.L. 1984. International testing of chickpeas for resistance to ascochyta blight. Plant Disease 68:782-784.

Singh, U. 1984. Dietary fiber and its constituents in desi and kabuli chickpea *(Cicer arietinum* L.) cultivars. Nutrition Reports International 29:419-426.

Singh, U. 1984. The inhibition of digestive enzymes by polyphenols of chickpea *(Cicer arietinum* L.) and pigeonpea *(Cajanus cajan* (L.) Millsp.). Nutrition Reports International 29:745-753.

Singh, U., Sahrawat, K.L., Jambunathan, R., and Burford, J.R. 1984. The use of hydrogen peroxide for the digestion and determination of total nitrogen in chickpea (*Cicer arietinum* L.) and pigeonpea *(Cajanus cajan* L.). Journal of the Science of Food and Agriculture 35:640-646.

Toomsan, B., Rupela, O.P., Mittal, S., Dart, P.J., and Clark, K.W. 1984. Counting *Cicer Rhizobium* using a plant infection technique. Soil Biology and Biochemistry 16:503-507.

Conference Paper

Smithson, J.B. 1984. ICRISAT's research on chickpea. Pages 20-23 *in* Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

PIGEONPEA

Contents

Cover photo: Harvesting pigeonpea ICPL 87. Recommended for release in peninsular India, this short-duration cultivar with wide adaptability is capable of producing 3800 kg ha^{-1} in two harvests.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Annual Report 1984. Patancheru, A.P. 502324, India: ICRISAT.

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PIGEONPEA

The Pulses Improvement Program continued to develop genetic stocks, broadbased populations, lines, and cultivars of short-, medium-, and long-duration pigeonpea, with a view to providing higher and more stable yields in the SAT. This report covers data collected in 1984, mostly from crops sown in 1983.

Our activities were concentrated at three locations: ICRISAT Center at Patancheru (18°N, 78°E, 800 mm mean annual rainfall), where emphasis was on medium-duration types for intercropping with major cereals in central and peninsular India; Hisar (29°N, 75°E, 450 mm rainfall), where short-duration types were researched as sole crops with limited irrigation in pigeonpea-wheat rotations, a new cropping system for northwestern India; and Gwalior (26°N, 78°E, 840 mm rainfall), where emphasis was on long-duration types for intercropping in the Indo-Gangetic Plain.

Rainfall at ICRISAT Center and Gwalior during 1983/84 was generally favorable for crop growth, but the weather was abnormally dry at Hisar. At Hisar the crop had unusually high insect damage and at Gwalior the crop suffered from frost.

Physical Stresses

Intensive Cropping of Early Pigeonpea

Early pigeonpea produces similar first-harvest yields in both peninsular and northern India. However, because of milder winters in peninsular India and the perennial nature of pigeonpea, ratoon harvests may be taken in this region (ICRISAT Annual Report 1983, p.171). Thus total yields from multiple harvests of early cultivars may exceed yields of medium-duration cultivars adapted to peninsular India. In order to determine the yield potential of early pigeonpea, we conducted experiments at ICRISAT Center to determine optimum plant densities, sowing date, and irrigation regime.

On an Alfisol, the cultivars ICPL 4, ICPL 81, and ICPL 87 were each grown at 20, 36, and 56 plants m^{-2}. There were two irrigation treatments, zero and optimal. The crop was sown on 23 June, 1983. Rainfall was adequate, so irrigation was not necessary until after the first harvest. In another experiment on a Vertisol, ICPL 81 and ICPL 87 were grown at the same three plant densities but there were three sowing dates, 28 June, 27 July, and 22 August. No irrigation treatments were imposed on this soil.

Yield of the June sowing on the Alfisol was generally greater than on the Vertisol (Figs. 1 and 2). On the Alfisol, maximum yield of both ICPL 81 and ICPL 87 was obtained at 36 plants m^{-2} whereas the yield of ICPL 4 was highest at 56 plants nr^{2} (Fig. 1). Irrigation benefited the 2nd flush yield only in ICPL 87. On the Vertisol, closer spacing generally increased yield but it markedly decreased yield at later sowings (Fig. 2). Podfly *{Melanagromyza obtusa)* damage limited 2nd-harvest yields and prevented a 3rd harvest. Nevertheless, the total yield of ICPL 87 on the Alfisol without irrigation still reached 3500 kg ha^{-1}. The results clearly demonstrate the need for early sowing and high plant densities to optimize yield in these cropping systems.

Screening for Salt Tolerance

Even though we have developed a field-screening method to identify pigeonpea genotypes tolerant to soil salinity (ICRISAT Annual Report 1979/80, p.108), field heterogeneity limits the number of lines that can be simultaneously screened. We have therefore evolved a pot-screening technique to detect genotypic differences at the seedling stage. The technique

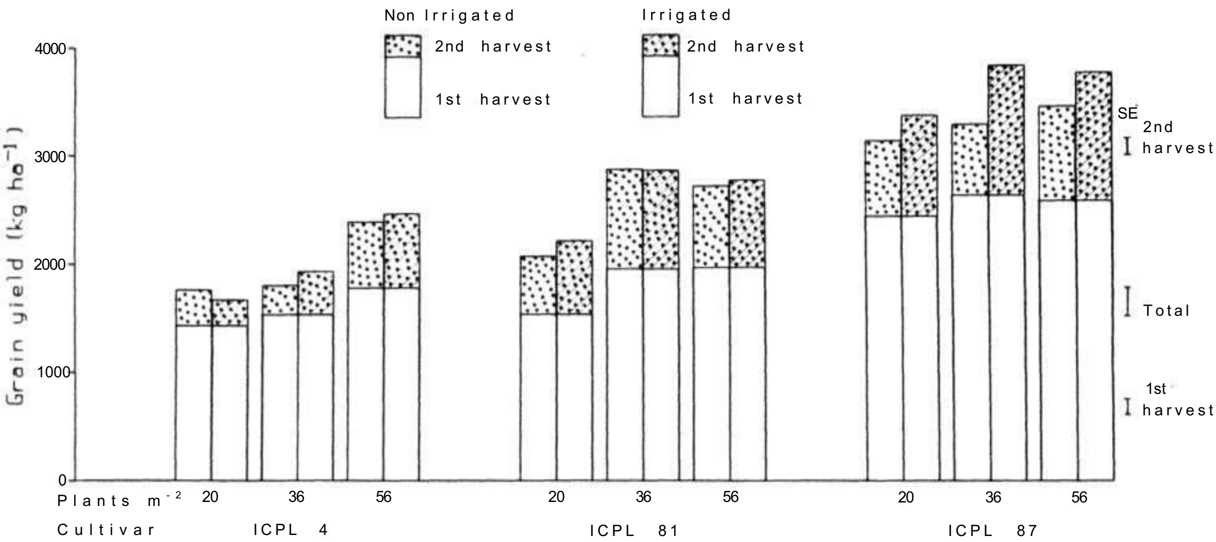


Figure 1. Grain yield (kg ha^{-1}) from 1st and 2nd harvests of three early pigeonpea cultivars grown at three plant densities on an Alfisol, ICRISAT Center, 1983/84.

involves mixing saline/alkaline soils with normal soil to achieve the required electrical conductivity. Uniform soil mixtures can then be added to pots allowing large numbers of genotypes to be screened. Differences in salinity tolerance obtained by this method are of the same order as previously obtained in the field; for example, C 11 is a tolerant, and Hy 3C a susceptible cultivar.

Response to Phosphorus

Previous field studies have shown that pigeonpea does not respond to phosphorus, either sprayed onto leaves (ICRISAT Annual Report 1979/80, p. 107) or applied to soil (ICRISAT Annual Report 1981, p. 138), in soils with medium levels of available phosphorus. However, in a pot experiment with an Alfisol

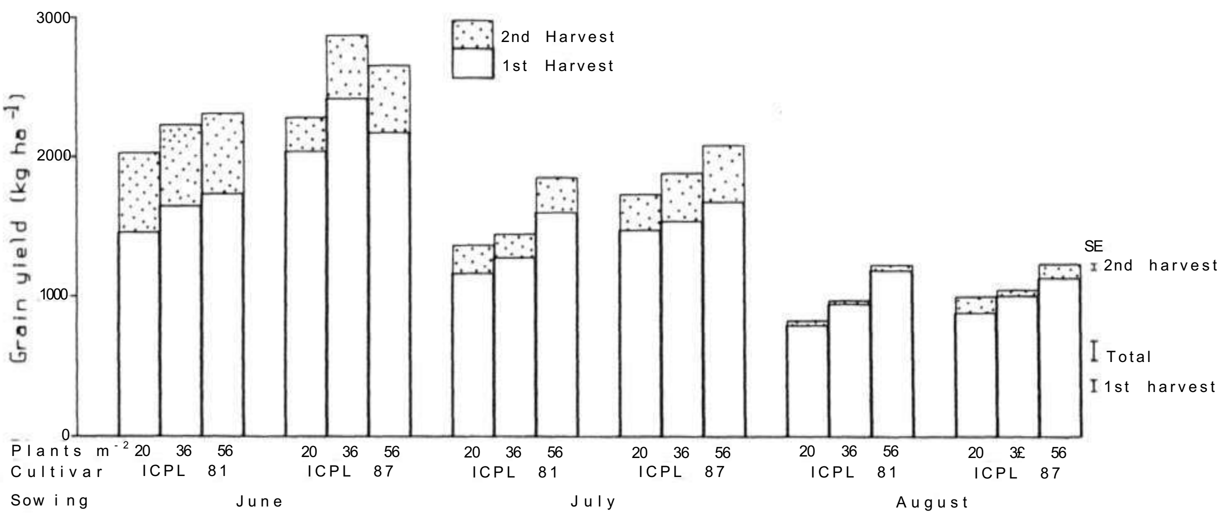


Figure 2. Grain yield (kg ha^{-1}) from 1st and 2nd harvests of two early pigeonpea cultivars grown at three plant densities and three sowing dates on a Vertisol, ICRISAT Center, 1983/84.

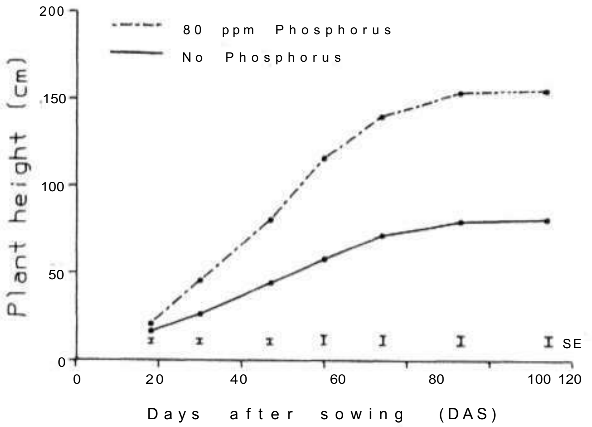


Figure 3. Changes in plant height (cm) of pigeonpea cultivar ICPL 6 over time with 0 and 80 ppm phosphorus applied to an Alfisol in pots, ICRISAT Center, 1984.

containing <1.5 ppm Olsen-available phosphorus, we obtained a significant response to soil application of 80 ppm phosphorus in ICPL 6 (Fig. 3). The response showed in early growth, before roots would have been able to fully exploit the soil mass in the pot, and intensified with time. The absence of applied phosphorus delayed maturity by 9-10 weeks and lowered seed yield from 14.9 to 1.2 g $plant^{-1}$. This result highlights the need for further studies of the interactions between phosphorus nutrition and other possible limiting factors, such as soil-water status.

Biotic Stresses

Diseases

Fusarium Wilt *(Fusarium udum)*

Screening for resistance. We continued to screen germplasm accessions, progenies, and advanced lines in wilt-sick plots at ICRISAT Center to identify wilt-resistant accessions and lines. Material was screened in wilt-sick plots on Vertisols and Alfisols where susceptible control lines showed more than 80% wilt incidence. We selected lines showing less than 20% wilt in the first screening and less than 10% in subsequent screens. A set of 363 new germplasm accessions received from our Genetic Resources Unit was screened in the wilt-sick plot. Of these, 15 accessions showed less than 10% wilt. Of the 129 germplasm selections (1982/83) screened in wilt-sick plots on an Alfisol, four, ICP 7445, 7490, 7789, and 12082, were found resistant. Fifteen selections from crosses between ICP 616, 1680, 4784, 6654, 6974, 11308, 11368, and 11405 showed resistance to wilt for the 3rd consecutive year.

Of the 20 *Heliothis-resistant* selections screened, 10 showed less than 10% wilt. They were ICP 3700, 4769, 5036, 5498, 5651-1-530, 6831, 7194-1-540, 7998, 7445-E3, and GW 3.

A large amount of breeding material, including F_2, F_3, and F_5 populations, F_3 single-plant progenies, F_5 bulks and advanced lines, entries included in the Medium-Maturity Pigeonpea Wilt Resistant Lines Yield Test (MPWRY), and Medium-Maturity Pigeonpea Unselected Bulks (MPUB), were screened in the wilt-sick plot. In MPWRY, ICPL 335 showed low wilt incidence (1.6%), and in the late-maturity advanced lines, ICP 8131-B-B⊗-GB⊗-GB⊗ remained wilt-free. Promising materials were advanced for further testing.

Pigeonpea wilt is seedborne. We reported earlier (Pulse Pathology (Pigeonpea) Report of Work, 1982/83) that *F. udum,* the pathogen causing pigeonpea wilt, could not be isolated from seeds of ICP 1, 231, 2376, 6997, and LRG 30, all highly susceptible to wilt. Later we detected the fungus in seeds of wilt-tolerant pigeonpea lines. Further studies confirmed that *F, udum* is internally seedborne in BDN 1, ICP 1903, and ICPX 78148. These results indicated that *F. udum* is not seedborne in all pigeonpea cultivars. We are studying the effects of fungicidal seed treatments to eradicate the internal seedborne inoculum.

Sterility Mosaic

Nature of the causal agent. We continued our efforts to determine the nature of the pathogen causing sterility mosaic (SM) disease using several new extraction media and purification procedures. As in the past, long, thin, flexuous, rod-shaped, virus-like particles were observed but only in a few partially-purified preparations. Results of serological tests of the crude sap and partially-purified preparations from SM-affected leaves with antisera of two closteroviruses (apple chlorotic leaf spot and apple stem-grooving viruses) were negative. Sap transmission of SM pathogen was again unsuccessful.

Healthy mite colony. A healthy (pathogen-free) colony of *Aceria cajani*, vector of the SM pathogen, was successfully maintained on BDN 1, a highly-susceptible pigeonpea cultivar. No SM symptoms were produced.

Mite multiplication. Mites were unable to multiply on three of the 10 SM-resistant and one of the four SM-tolerant pigeonpea lines. Mites in low numbers were detected on the remaining seven SM-resistant and three SM-tolerant lines. Of the four SM-susceptible lines tested, BDN 1 supported maximum mite population (3.5 mites cm^{-2} leaf area) followed by ICP 1 (1.5 mites), T 21 (1.1 mites), and C 11 (0.2 mites). None of the four SM-resistant *Atylosia* spp tested allowed any mite multiplication; however, only one of the three SM-susceptible *Atylosia* spp, *A. cajanifolia* , that showed severe mosaic symptoms, supported mite multiplication.

Mite survival during the summer season. In the past we found that mites were unable to survive on pigeonpea during the hot summer season at ICRISAT Center. As a result of observations on several possible plant species, we found that mites could survive on leaves of *A. scarabaeoides* growing under the shade of mango trees and near flooded rice fields, but not on those growing in open fields near mango trees. These mites were, however, noninfective. This confirmed our earlier observations and experience that mites prefer a moist and humid environment for multiplication and survival. We will continue to search for plant species on which infective mites can survive naturally in the summer season, to help us understand the annual recurrence of the disease.

Screening for resistance. As in 1983, we screened a large amount of pigeonpea material including germplasm accessions, progenies, and advanced lines in the SM nursery, using the infector-hedge technique developed at ICRISAT Center.

We confirmed resistance in 16 progenies from the 1979 resistant germplasm accessions, 54 progenies from the 1980 germplasm selections, 16 progenies from the 1981 resistant germplasm accessions, and 100 accessions from the 1982 germplasm selections. Of the 160 new germplasm accessions tested, 38 were free from the disease. None of the 15 *Heliothis*- and podfly-resistant lines tested for the first time was free from disease; only one line (ICP 4769) showed

Sterility mosaic symptoms on pigeonpea, showing susceptible plant (right), stunted and without flowers compared to resistant plant (left).

less than 4% SM. Of the five lines selected from the 1980 and the 1981 All India Coordinated Varietal Trials (Arhar Coordinated Trial ACT), three (AL 15, ICPL 235, and MA 97) were resistant to SM. Only four (Arhar 20 (105), Bahar, DA 11, and MA 166) of91 entries included in the 1983 ACTs were free from the disease.

Phytophthora Blight *(Phytophthora drechsleri* f.sp *cajani)*

Epidemiological studies. We studied the spread of fungal inoculum by wind, splashing rain, and rain water in the *Phytophthora*-infested disease nursery. Results indicated that wind and splashing rain contribute to dispersal of the fungus inoculum within a crop. Also rain water running through a *Phytophthora-infested* field may carry the inoculum with it.

Phytophthora blight control by metalaxyl. We tested three methods of applying metalaxyl in different formulations of Ridomil® as seed dressing (SE), soil application (SO), and spray (SP) separately, and in combination, for the control of phytophthora blight. The experiment was conducted in 4 x 3m plots (four 4-m rows plot^{-1}) in a factorial design with three replications during the 1983 rainy season in the ICRISAT multiple-disease nursery, where a high and uniformly-distributed population of the P2 (Hyderabad) isolate of the pathogen is known to exist. Two pigeonpea lines, Hy 3C, susceptible, and ICP 1, tolerant, to the P2 isolate of *Phytophthora drechsleri* f. sp *cajani* (Pdc) were sown in the trial. The treatments were: seed dressing using a slurry containing 5 g metalaxyl active ingredient (a.i.) kg^{-1} seed; soil application in the rows just before sowing at 12 g a.i. metalaxyl as granules plot^{-1}; and 500 mL sprays containing 1.5 g a.i. metalaxyl plot^{-1} applied three times, at 40, 55, and 70 DAS.

As expected, more severe blight was recorded in Hy 3C than in ICP 1 plots (Figs. 4,5,6, and 7). Seed dressing alone was ineffective in controlling the disease, as the progress of the blight in control plots was similar to that in plots with seed dressing. The spray treatment alone, and in combination with seed dressing, was most effective in controlling blight. Metalaxyl when applied as spray was more effective on the tolerant line ICP 1, where we recorded about 23% blight compared to 86% in the untreated control.

Interaction between mycorrhiza and *Phytophthora.* Vesicular-arbuscular mycorrhizae (VAM) have been reported to decrease disease incidence caused by soilborne fungi. *Gigaspora calospora,* a species of VAM isolated from pigeonpea, was tested for its effect on phytophthora blight development. The greenhouse study included inoculation by VAM and Pdc separately and together; a control without either VAM or Pdc; and two more treatments, (for details see Table 1 footnotes). The study was repeated using 10 g pot^{-1} press-dried mycelia (pressed with a spatula to drain excess water) in Expt. 1 and 5 g pot"1 press-dried mycelia in Expt. 2. Five seeds were sown in each pot. There were four replications for each treatment and the pots were randomly placed on greenhouse benches. We recorded the number of seedlings that emerged and those with blight.

In Expt. 1, all the treatments inoculated with Pdc at the time of sowing had low seedling emergence, indicating high pre-emergence damping-off (Table 1). To achieve a better emergence the inoculum was reduced from 10 g pot^{-1} to 5 g pot^{-1} in Expt. 2. In both the experiments, treatments with Pdc inoculation (alone, with, or followed by VAM) at sowing had a high percentage of blighted plants, while treatment with VAM applied at sowing and followed by Pdc had a lower percentage of blighted plants. These results are being checked in further experiments.

Breeding for Disease Resistance

We screened populations from 40 crosses and 102 advanced lines in the wilt-sick nursery, from 60 crosses and 356 advanced lines in the SM nursery, and from 36 crosses and 103 advanced lines in the multiple disease nursery. This year we concentrated on crosses involving long-duration pigeonpea. Using line * tester mating designs we made 18 crosses to incorporate wilt resistance

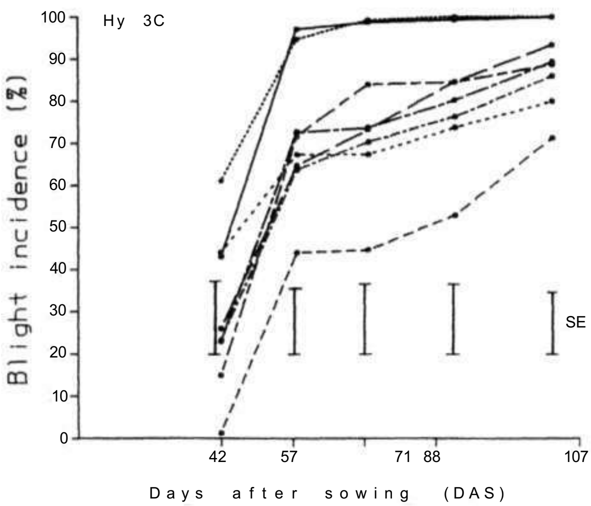


Figure 4. Effect of mode of application of Ridomil® on the incidence of phytophthora blight in Hy3C, a blight-susceptible pigeonpea cultivar, ICRISAT Center, 1984.

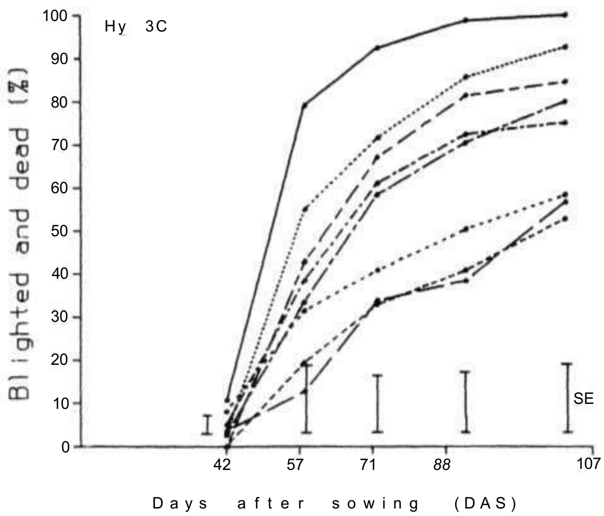


Figure 5. Effect of mode of application of Ridomil® on mortality of Hy 3C pigeonpea seedlings from phytophthora blight, ICRISAT Center, 1984.

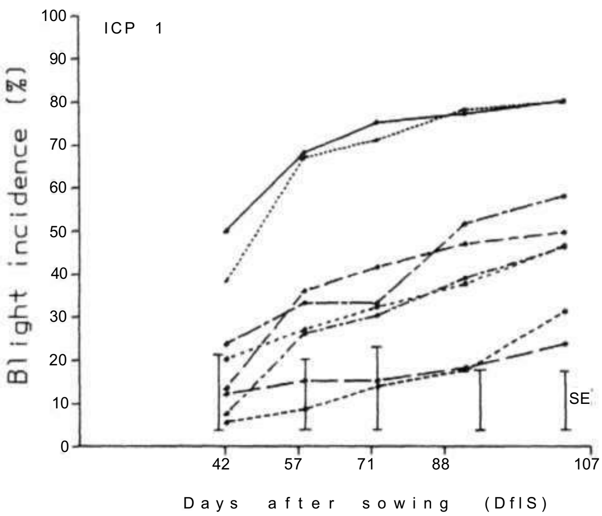


Figure 6. Effect of mode of application of Ridomil® on the incidence of phytophthora blight in ICP 1, a blight-tolerant pigeonpea cultivar, ICRISAT Center, 1984.

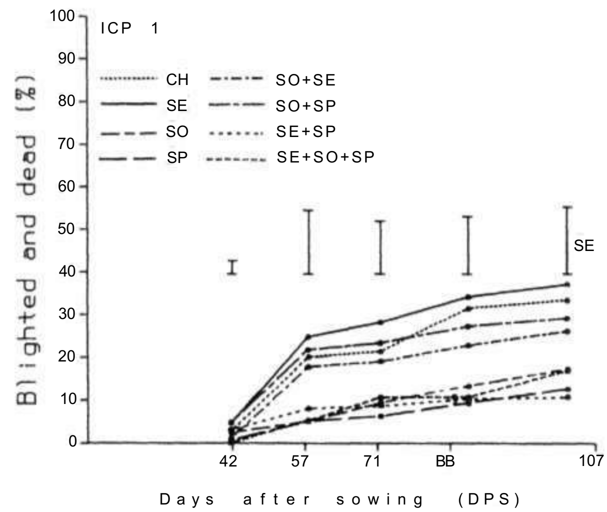


Figure 7. Effect of mode of application of Ridomil® on mortality of pigeonpea ICP 1 seedlings from phyto phthora blight, ICRISAT Center, 1984.

Treatments

CH = control, nontreated.

SE = slurry seed dressing, 5 g a. i. metalaxyl (Ridomil 72® WP) kg^{-1} seed.

SO = soil application, 12 g a. i. metalaxyl (Ridomil 5G®) $plot^{-1}$ as granules before sowing.

SP = 500 mL aqueous foliar spray 1.5 g a. i. metalaxyl (Ridomil 72® WP) $plot^{-1}$ at 40, 55, and 70 DAS.

Plot size 4 x 3 in for all treatments.

Table 1. Effect of *Phytophthora drechsleri* f.sp *cajani* (Pdc) and vesicular-arbuscular mycorrhiza (VAM) on seedling emergence and incidence of phytophthora blight in pigeonpea cultivar Hy 3C. Greenhouse study, ICRISAT Center, 1983/84.

	Expt P		Expt 2[1]	
Treatment[3]	Emerged[2]	Blighted[2]	Emerged	Blighted
Control	18	0	18	0
Pdc	8	6	19	11
VAM	20	0	19	0
Pdc + VAM	12	8	19	13
Pdc-VAM	12	10	19	13
VAM - Pdc	20	3	20	9

1. Expt 1: 10 g pot^{-1} *Phytophthora* mycelium applied. Expt 2: 5 g pot^{-1} *Phytophthora* mycelium applied. Total of 20 seeds sown in 4 pots, 5 seeds pot^{-1} in both experiments.
2. Emerged = number of seedlings emerged. Blighted = number of seedlings showing blight symptoms.
3. Control = No Pdc or VAM. Pdc = Pdc applied at sowing. VAM = VAM applied at sowing. Pdc + VAM = Pdc and VAM applied at sowing. Pdc - VAM = Pdc applied at sowing, VAM applied 15 days after sowing (DAS). VAM - Pdc = VAM applied at sowing, Pdc applied 15 DAS.

and 24 crosses to incorporate SM resistance. We also made 11 crosses or backcrosses for a study on the inheritance of alternaria blight resistance.

In yield trials containing 18 Medium-Maturity Pigeonpea Unselected Bulk (MPUB) populations developed from seed taken from resistant plants of these populations in the wilt nursery for 3 years, eight populations yielded on average as much or more than the control ICPL 295 (Table 2). When grown in the wilt-sick nursery at ICRISAT Center all but one of the 18 lines outyielded the control. On the basis of their yield and wilt resistance, nine lines have been advanced for further trials. These bulks provide ideal material for selecting high-yielding lines that have a high probability of being wilt-resistant.

The Medium-Maturity Pigeonpea Wilt-Resistant Yield Trial (MPWRY) was grown at five locations. Of the 22 entries, 18 were ICRISAT lines. ICPL 227 and 270 averaged 1660 and 1620 kg ha^{-1} compared with 1580 kg ha^{-1} for the control, ICPL 131 (a C 11 selection) under normal field conditions.

In the Medium-Maturity Pigeonpea Sterility Mosaic Resistant Yield Trial (MPSRY) 20 of the 24 lines were from ICRISAT Center. Good results were obtained from three locations. Three lines, ICPL 345, 8346, and 342, averaged 1695, 1605, and 1550 kg ha^{-1} compared with 1510 kg ha"[1] for the control, ICPL 131 (a C 11 selection) under normal field conditions.

In our advanced line test grown under normal field conditions, eight lines yielded between 1240 and 2050 kg ha^{-1}, had seed size between 9.7 and 11.8 g/100 seeds, and had 4 to 13 % wilt in the wilt-sick plot. In comparison, the control ICPL 131 yielded 1100 kg ha^{-1}, had 10.8 g/100 seeds, and 59% wilt. These eight lines were advanced to the MPWRY.

These results suggest that it should be possible to identify disease-resistant lines with yields comparable to the control variety C 11 under normal field conditions even where there is little or no disease. Under disease pressure the disease-resistant lines will, of course, have a marked advantage.

We continued to stress the need for high-yielding short-duration lines with SM resistance as presently no released extra-early varieties have resistance to this disease. Of 128 advanced resistant lines we have identified 28 for yield testing and 83 for further assessment. We also advanced 45 F_2 bulks, both determinate and indeterminate types, for yield trials as well as further screening.

Table 2. Summary of performance of entries in Medium-Maturity Pigeonpea Unselected Bulk (MPUB) yield trial grown at three Indian locations, 1983.

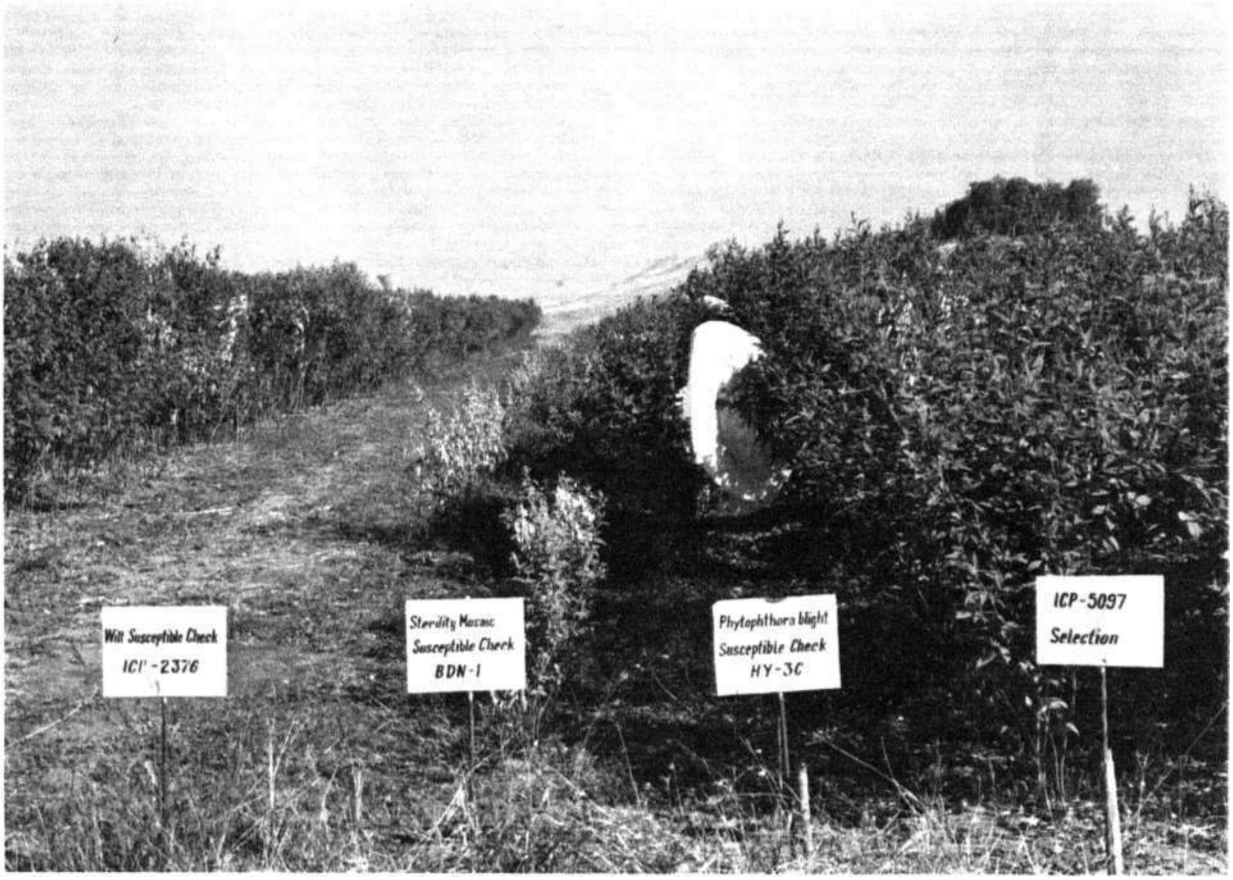
Entries	Days to flowering	Days to maturity	Plant height (cm)	100-seed mass (g)	Yield (kg ha^{-1}) ICRISAT Center[1]	Bharuch	Baroda	Mean	Wilt[1] (%)
78191 WB-WB-WB	135	192	136	8.8	1470 (4)[2]	940 (4)	2080 (2)	1496	30
78120 WB-WB-WB	126	182	143	9.3	1610 (1)	780 (12)	1860 (4)	1413	32
78153 WB-WB-WB	133	192	145	9.3	1590 (2)	890 (7)	1430 (18)	1304	29
78148 WB-WB-WB	136	192	128	7.5	1470 (3)	750 (14)	1640 (14)	1287	41
78223 WB-WB-WB	133	190	123	8.9	1360 (5)	790 (10)	1680 (8)	1276	31
78140 WB-WB-WB	130	188	140	8.7	1000 (15)	970 (2)	1780 (7)	1250	47
78139 WB-WB-WB	130	193	143	9.6	1310 (6)	800 (9)	1620 (11)	1244	37
78179 WB-WB-WB	133	188	128	10.2	1180 (8)	650 (18)	1780 (6)	1201	33
Control									
ICPL 295 (C 11 sel)	135	197	122	9.3	820 (18)	900 (6)	1890 (3)	1201	31
78143 WB-WB-WB	142	210	125	10.7	1140 (10)	940 (5)	1460 (15)	1180	26
78167 WB-WB-WB	133	190	137	8.6	1140 (11)	820 (8)	1590 (13)	1179	43
78213 WB-WB-WB	144	213	129	8.2	1180 (7)	680 (17)	1630 (10)	1165	20
78231 WB-WB-WB	142	203	130	10.5	1120 (12)	790 (11)	1460 (17)	1114	27
78204 WB-WB-WB	135	200	120	7.3	990 (16)	730 (15)	1590 (12)	1105	49
78130 WB-WB-WB	131	185	143	10.6	1160 (9)	1050 (1)	1000 (21)	1070	30
78227 WB-WB-WB	138	193	130	11.5	1050 (14)	610 (20)	1500 (14)	1053	18
78142 WB-WB-WB	137	197	127	9.2	900 (17)	760 (13)	1450 (16)	1037	25
78178 WB-WB-WB	136	203	119	10.0	790 (19)	720 (16)	1780 (5)	1098	43
78180 WB-WB-WB	137	197	137	10.3	1090 (13)	620 (19)	1370 (19)	1025	29
SE	±2.1	±4.4	±3.5	±0.31	±114	±73	±258		±4.4
Trial mean	135	195	132	9.4	1153	808	1624		31
CV(%)	3	4	5	6	17	16	28		22

1. Recorded from wilt-sick nursery at ICRISAT Center. Mean of four replications, each with approximately 66 plants.
2. Numbers in parentheses indicate rank within trial.

Multiple Disease Resistance

We continued to screen breeding material in our multiple disease nursery for combined resistance to all three major pigeonpea diseases, wilt, SM, and the P2 and P3 isolates of phytophthora blight.

Of the 16 single-plant selections of ICP 5097 and ICPX 74360 screened, three lines had less than 20% wilt, SM, and blight when the corresponding susceptible controls showed an average of 77% phytophthora blight, 95% sterility mosaic and 95% wilt. Forty-five advanced selections from ICP 5097, 8094, ICPX 74360, and 74363 were screened. Three lines showed less than 10% and 14 showed 10-20% wilt, SM, and blight. Of the 95 F_3 single-plant selections from ICPX 80260, 80264, 80273, 80275, 80284, and 80289, four showed less than 10% and 14 showed less than 20% wilt, SM, and blight. Sixteen of the 36 F_3 bulks tested showed less than 20% incidence of all three diseases. Of the seven cultivars screened for the first time in the nursery, only NP(WR) 15 showed less than 10% wilt, SM, and blight. Selfed seed collected from SM- and wilt-resistant plants of four cultivars that showed tolerance to the P3 isolate will be retested during the coming season.



Screening for multiple-disease resistance in pigeonpea in a nursery at ICRISAT Center. Selection ICP 5097 (right) showed combined resistance to all three diseases in the experiment.

Since 1981, we have been screening the elite pigeonpea accessions and lines for multiple disease resistance according to requirements of different areas of India. Table 3 lists the accessions and lines with resistance/tolerance to more than one disease.

Nematode Diseases

Plant parasitic nematodes in pigeonpea at ICRISAT Center. We identified seven parasitic nematode species on pigeonpea in Alfisol and Vertisol fields. These were the cyst (*Heterodera cajani),* lance *(Hoplolaimus seinhorsti),* reniform *(Rotylenchulus reniformis),* stunt *(Tylenchorhynchus* sp), and spiral (*Helicotylenchus retusus)* nematodes observed in both Alfisol and Vertisol fields, the spiral nematode *(Helicotylenchus indicus)* only in Alfisols, and the lesion nematode (*Pratylenchus* sp), only in Vertisol fields. The pigeonpea cyst nematode was the predominant species found in pigeonpea sown in Vertisols, whereas the populations of reniform and lance nematodes were higher in the Alfisols.

Cyst nematode. A pure population of the cyst nematode *H. cajani* was maintained on pigeonpea ICP 2376 and cowpeas. The legume species *Atylosia, Dunbaria, Flemingia,* and *Rhynchosia* were susceptible to the cyst nematode, and are first host records for this nematode. A technique to develop nematode-infested soil in pots was

Table 3. Pigeonpea lines with combined multiple-disease resistance/tolerance.

Lines with combined resistance/tolerance to:	Line number
Four diseases	
Wilt, sterility mosaic[1], root knot, and alternaria blight	ICP 8861, 8862
Three diseases	
Wilt, sterility mosaic[2], and phytophthora blight[3]	ICP 5097, 8094, ICPX 74360 progenies
Wilt, sterility mosaic[2], and root knot	ICP 8860, 11291
Wilt, alternaria blight, and bacterial blight	ICP 8863
Wilt, phytophthora blight[3], and root knot	ICP 8865, 8866
Wilt, sterility mosaic[2], and alternaria blight	ICP 8867, 8869, 10960, 11288, 11296
Two diseases	
Phytophthora blight[3] and alternaria blight	ICP 2376, 2719
Sterility mosaic[2] and alternaria blight	ICP 2630, 4725, 7188, 7869, 7904, 7906, 8850, 8856, 8857
Sterility mosaic[2] and phytophthora blight[3]	ICP 8466, 11300, 11301, 11302, 11303, 11304
Wilt and root knot	ICP 8859, 11286, 11299
Wilt and phytophthora blight[3]	ICP 8868, 10958, 11287, 11294
Wilt and sterility mosaic[2]	ICP 11289, 11290, 11297, 11298

1. Resistant except in the Indian states of Bihar and Tamil Nadu.
2. Resistant except in the Indian states of Bihar, Karnataka, and Tamil Nadu. ICP 10976 can be used for resistance to sterility mosaic in all Indian states.
3. Resistant to the P2 isolate only.

standardized to initiate screening for resistance to *H. cajani.*

Insect Pests

Surveys

As usual the pod borer *(Heliothis armigera)* was the most damaging pest on pigeonpea in central and southern India in 1983/84. However the attacks by this insect were less severe than in most previous years. Although the medium-duration pigeonpeas that flowered and podded in November were severely damaged by this pest, pigeonpeas that flowered before or after November mostly escaped major damage. The podfly (*Melanagromyza obtusa)* appeared to be more prevalent than usual in some of the pigeonpea-growing areas that were visited in India (e.g. Gwalior and Hisar). Podfly infestations cannot be easily detected, because eggs are laid inside the pods and there are no visible symptoms of damage until adults emerge through the pod wall. It is therefore an underestimated pest. It causes substantial yield losses every year, particularly on the long-duration crops of northern and central India. *Tanaostigmodes cajaninae,* a hymenopteran insect which feeds inside pigeonpea pods (Fig. 8), again reached pest status at ICRISAT Center but was rare in all farmers' fields we surveyed. This insect thrives under research station conditions where pigeonpea pods are available from September to April each year and where endosulfan, used for the control of pod borer infestations, fails to control the hymenopteran pest but reduces its natural enemies. *Tanaostigmodes cajaninae* is at this time no more than a research station nui-

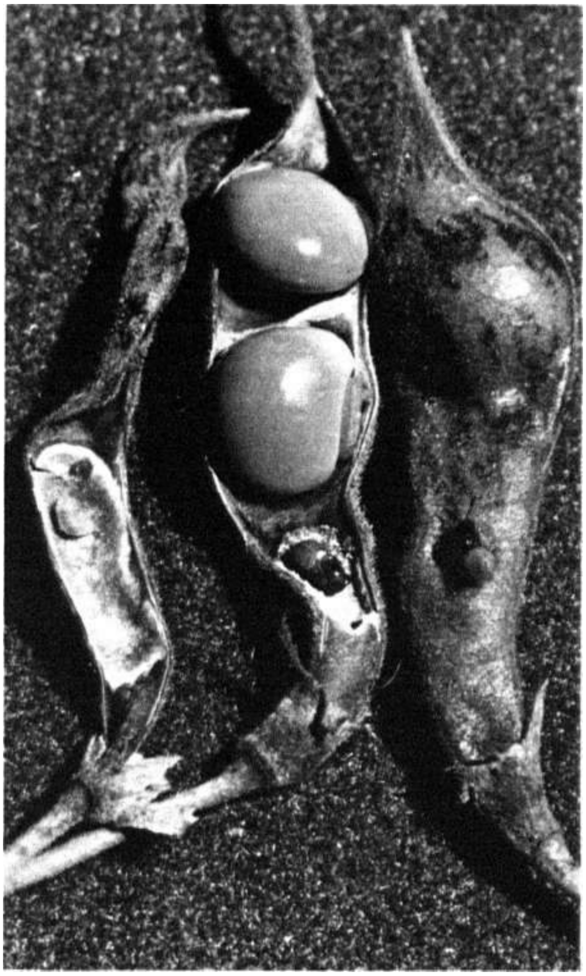


Figure 8. Larva, pupa, and adult of hymenopteran pest *Tanaostigmodes cajaninae* inside pigeonpea pods.

sance but it serves as a good reminder that changes in farming practices can promote relatively rare insects to pest status.

A tour of some countries in Southeast Asia revealed that *Heliothis armigera* was a widespread pest on pigeonpea and many other crops including cotton, maize, and several vegetables. Another pigeonpea pod borer (*Maruca testulalis)* was also seen to be very common and damaging. This insect is of sporadic importance in northern India but is known to be a regular major pest of pigeonpea in several countries, particularly Fiji. A very large number of other insect species were noticed on pigeonpea plants at all stages of growth but none appeared to be of economic importance at present.

Heliothis armigera

Population monitoring. A network of 113 pheromone traps that catch male *Heliothis armigera* moths has been set up to cover 60 locations in Bangladesh, India, Pakistan, and Sri Lanka. ICRISAT in collaboration with the Tropical Development and Research Institute (TDRI), London, provides traps and rubber septa loaded with synthetic pheromone to the national scientists at each location. These cooperating scientists count the numbers of moths caught each night and send information on trap catches to ICRISAT Center at the end of each month. We also receive data on catches of *H. armigera* and other insects in light traps set up at some of these locations.

Data from the network of pheromone traps operated for more than 2 years are now available and a post-doctoral scientist has been recruited to study and interpret them in cooperation with TDRI scientists. This study is still in its early stages and several statistical techniques are being tested in an attempt to maximize the information that can be derived from the available data. It is already obvious that a large number of environmental factors, including temperature, humidity, wind, moonlight, and local host-plant availability, play an important role in determining the numbers of moths caught in both pheromone and light traps. By a series of analyses it may be possible to develop correction factors that will reduce the very large variations in catches not attributable to changes in the local populations of moths, and so allow the data set to be useful in monitoring these populations.

Light trapping was initiated at ICRISAT Center in 1974 and records of *H. armigera* caught in traps have been collected nightly since then. Now that 10 years' data are available, clearly-defined cycles of catches recur in most years in spite of large variations in the catches of different traps. Almost every year there are peak catches of moths in August-September and in November-December separated by a dearth of

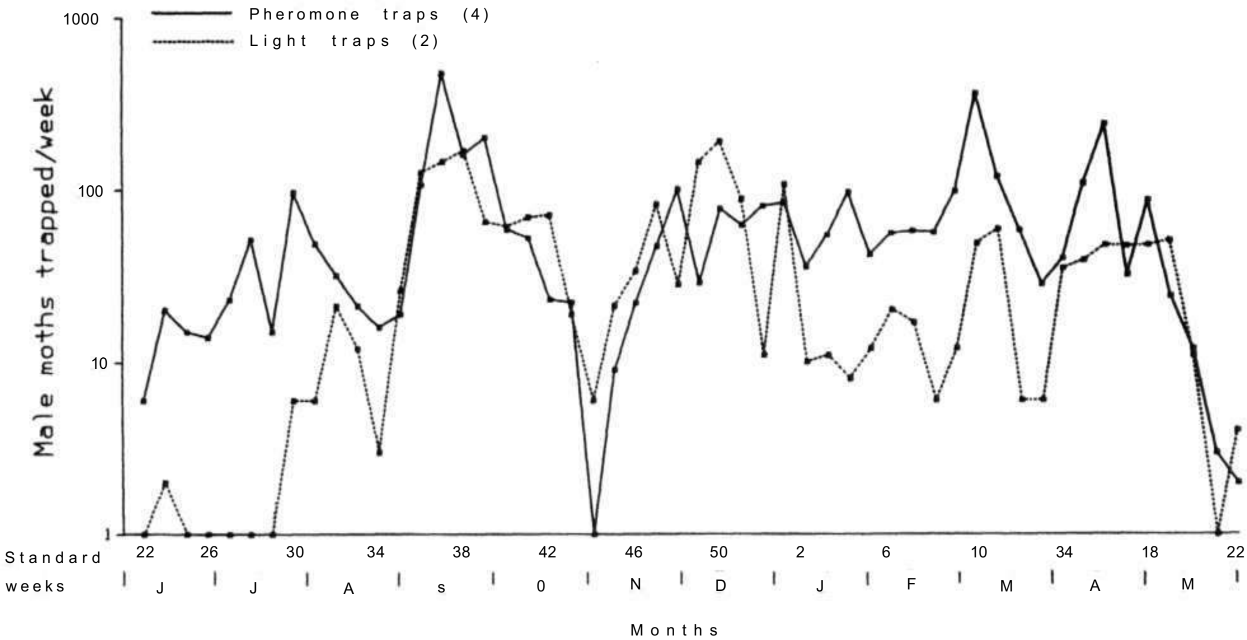


Figure 9. *H. armigera* moths trapped at ICRISAT Center, 1983/84.

moths in October (Fig. 9). It is probable that the earlier peak of moths trapped is associated with moths that have originated from larvae that have fed on sorghum, pearl millet, and groundnuts; and that the later peak is mainly associated with larvae feeding on pigeonpea and chickpea. We do not know why there are so few moths in October, but have noticed that pigeonpea flowering at that time can escape severe pest attack. It would be useful to grow a large area of pigeonpea that would flower and pod in October, to determine whether such a crop would escape damage, or whether the paucity of *H. armigera* at that time is normally the result of a scarcity of suitable hosts.

It is not yet clear whether migration plays an important role in the ecology of *H. armigera.* This year ICRISAT and TDRI scientists embarked upon an intensive migration study. By studying unusual surges in trap catches in relation to wind patterns, it should be possible to identify migration events and the sources of the moths. We acknowledge the excellent cooperation of the Indian Meteorological Department in providing the wind charts required for such studies.

Host plant resistance. We have completed screening the germplasm accessions available at ICRISAT having tested 8400 in open field trials. Although we found no genotype with sufficient resistance to withstand heavy infestations of *H. armigera* without suffering severe damage, there are clear differences in susceptibility. Breeders and entomologists are currently engaged in an extensive breeding and selection effort that is directed towards increasing the levels of resistance that have been discovered in germplasm accessions. Earlier attempts to combine the antibiosis to this pest, that was clearly evident in *Atylosia scarabae aides,* with the agronomic- and consumer-required qualities of pigeonpea have led to the selection of some promising intergeneric derivatives. However, this approach does not appear to have been more productive than simple selection from the available pigeonpea germplasm accessions.

In previous years our efforts were concentrated towards selection for resistance within the medium-duration genotypes, as this then appeared to be the duration with the most potential. However, it has become increasingly obvious that short-duration pigeonpeas have greater potential, particularly in northern India. Consequently, increased attention is now being paid to the search for resistance within this maturity group. Of the 65 short-duration genotypes selected previously as appearing to possess some resistance, only 30 appeared promising at ICRISAT Center and 9 at Hisar when tested this year. Of these, only five did well at both locations. This result illustrates the need to select and test genotypes at more than one location and over a series of seasons.

The development of genotypes that show exceptionally good compensation for pest damage continued, and our selection from APAU 2208 again proved to be outstanding.

We continued to make progress in our collaborative study with the Max-Planck Institute of Biochemistry, Munich, on the mechanisms of resistance. One exciting finding in Munich was that the moths appear to be able to differentiate between resistant and susceptible genotypes for oviposition, even when those genotypes are still in the seedling stage. Although we have not yet managed to detect clearly such differences between seedlings at ICRISAT Center, we will give increased attention to this approach. The ability to select for resistance at the seedling stage in the laboratory, rather than relying on open field screening at the podding stage, would greatly accelerate and facilitate our progress.

Biological control. Previous work at ICRISAT Center has shown that *H. armigera* eggs collected from sorghum are heavily parasitized by *Trichogramma chilonis,* but eggs collected from pigeonpea have little or no parasitism. Studies in the laboratory have also indicated that eggs on pigeonpea are less attractive to *T. chilonis* than are those on sorghum. There was speculation that pigeonpea genotypes that are most susceptible to the hymenopteran pest *Tanaostigmodes cajaninae* may also be attractive to these hymenopteran parasites. Consequently in 1983/84 we compared *T. chilonis* parasitism rates in eggs placed on genotypes that were resistant and susceptible to the hymenopteran pests in our laboratory tests. We used eggs of *Corcyra cephalonica* in these tests since they can be easily reared in laboratory cultures, and are readily parasitized by *Trichogramma* spp. We used 25-30 eggs site^{-1} and repeated the experiment eight times. The percentages of the eggs that were parasitized in these tests are shown in Table 4. It can be seen that differences between the genotypes were small and insignificant, but that there was a very large reduction in parasitism in the eggs placed on the pods. Further study of the apparent deterrent effect of the pods on egg parasitism will be conducted. This phenomenon is important, as many *H. armigera* eggs are laid on young pigeonpea pods in the field.

Table 4. Parasitism by *Trichogramma chilonis* in eggs of *Corcyra cephalonica* placed on leaves, flowers, and pods of pigeonpea genotypes known to be resistant or susceptible to *Tanaostigmodes cajaninae,* in laboratory tests, ICRISAT Center, February 1984.

	Eggs parasitized (%)	
Plant part	Resistant	Susceptible
Leaf	94.9 (76.9 x 8.2)[1]	96.4 (79.0 x 8.2)[1]
Flower	88.2 (69.9 x 4.9)	99.9 (88.2 x 4.9)
Pod	3.3(10.5 x 2.8)	3.6(11.0 x 2.8)

1. Figures in parentheses are arc sine transformed values, along with SEs.

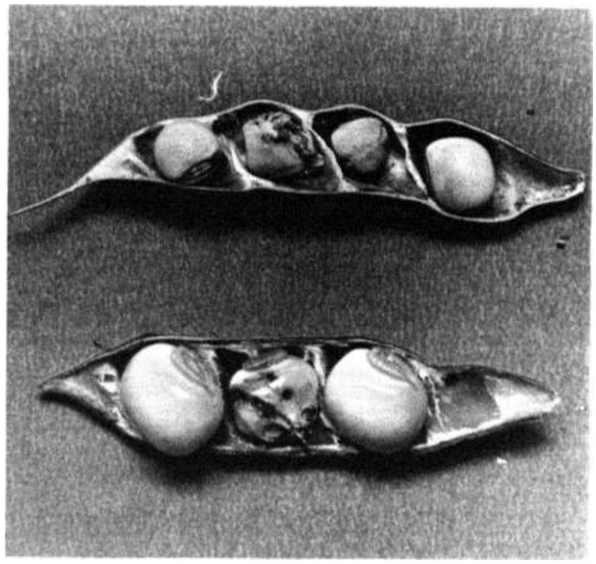
Podfly (*Melanagromyza obtusa*)

Importance and insecticide use. Although the podfly is most damaging on long-duration cultivars that are widely grown in northern and central India, it can also cause substantial yield loss in the short-duration genotypes that appear to have a productive future in many areas of India. In 1984 we identified a major podfly problem on the very productive new cropping system in which two or three harvests are taken from short-duration pigeonpeas. In spite of intensive protection with endosulfan, the 2nd and 3rd harvests from such genotypes at ICRISAT Center were severely damaged by podfly, with more than half the pods infested. Endosulfan is primarily used to control *H. armigera* but has been recommended for use against podfly in northern

India. Experiments at ICRISAT Center have shown that endosulfan is not very effective in controlling podfly. Alternative insecticides with some systemic action, such as dimethoate and monocrotophos have been shown to give much better podfly control. However, the need to use two insecticides to control pod borer and podfly may hamper the extension of the very productive multi-harvest system. This emphasizes the need to find alternatives to using pesticides to control the pest complex on pigeonpea.

Host plant resistance. Our search for plant resistance to podfly has identified several genotypes that have consistently reduced infestations compared to the commonly-grown cultivars (Table 5). Unfortunately, the levels of resistance found are not normally sufficient to result in detectable yield advances, so breeders and entomologists are utilizing these genotypes in attempts to intensify the resistance and to combine it with other desirable characters.

Our attempts to determine the mechanisms of



Podfly-damaged pigeonpeas; the eggs, larvae, and pupae develop inside the pod so there is no external evidence of infestation until the adult fly emerges through the pod wall.

Table 5. Relative resistance rating (RRR)[1] in pesticide-free conditions of pigeonpea selections found resistant to podfly (M. *obtusa*), ICRISAT Center, 1979-1984.

Pigeonpea selections	Days to 50% flowering	1979/80	1980/81	1981/82	1982/83	1983/84	Mean RRR
T 21 (control)	87	6	6	6	6	6	6.0
ICP 909 E3	95	2	2	3	4	5	3.2
1918(IG)4EB	99	2	2	6	7	3	4.0
ICP 3328 E3	105	2	3	4	3	3	3.0
ICP 1691 E1	113	6	2	4	3	5	4.0
ICP 7050 E1	117	2	2	2	6	3	3.0
ICP 10466 E3	118	3	3	7	3	4	4.0
ICP 10531 E1	119	2	2	3	2	2	2.2
C 11 (control)	119	6	6	6	6	6	6.0
ICP 6977 E1	120	3	2	NT[2]	NT[2]	2	(2.3)[3]
ICP 7941 E1	129	2	2	4	2	3	2.6
ICP 7946 E1	132	2	3	3	3	4	3.0
NP(WR) 15 (control)	132	6	6	6	6	6	6.0
ICP 8102-5 S1	134	4	3	3	4	6	4.0
ICP 7194-1 S4	147	4	4	4	4	4	4.0
ICP 7176-5	162	4	4	3	5	5	4.2

1. RRR = Relative resistance rating compared to standard controls on a 1-9 scale, where 1 = absolute resistance, 9 = highly susceptible.
2. NT = Not tested.
3. Calculated from three seasons' data only.

resistance to podfly continued. The most susceptible genotypes are generally those with larger pods. Differences in pod wall thickness and toughness, and in the density of glandular hairs on the pod surface have been found among both resistant and susceptible genotypes, but no single factor has as yet been identified as consistently associated with resistance.

Breeding for Insect Resistance

During this year we continued our emphasis on accumulating resistance to *Heliothis* and podfly, and on improving the yield of resistant material. Unfortunately we experienced a *Heliothis* attack in our segregating populations which was so severe that it was difficult to select resistant plants. Among our progeny rows and bulks we selected 1447 single plants as follows; 1320 in the F_2, 85 in the F_3, and 42 between the F_4 and F_7 generations. We advanced 97 F_1s under sprayed conditions for selection in the F_2 and grew two trials with 15 F,s in each, one to determine the reaction to *Heliothis* and the other to determine the reaction to podfly in relation to resistant and susceptible parents. We made 22 new crosses.

The two *Heliothis* -resistant lines we identified last year from the cross ICPX 76239 (ICP 1900-11 x BDN 1) (ICRISAT Annual Report 1983, pp. 164-165) have been designated ICPL 84060 and ICPL 84061. They ranked 1st and 2nd under sprayed conditions in a trial with other resistant and susceptible germplasm lines (Table 6). ICPL 84060 also gave a high 1st harvest yield in the unsprayed field. Both lines had relatively low pod damage to 1st harvest pods. We have entered these two lines along with four other selections, ICPL 84062, 84063, 84064, and 84065

Table 6. Performance of *Heliothis-resistant* and-susceptible pigeonpea lines grown under sprayed and nonsprayed conditions, ICRISAT Center, rainy season 1983.

		Non-sprayed	Sprayed		Grain yield (kg ha^{-1})			Pods bored (%)	
						Nonsprayed			
ICPL	Pedigree	Days to flowering	Plant height (cm)	100-seed mass (g)	Sprayed	1st harvest	Total (2 harvests)	1st harvest	2nd harvest
84060	ICPX 76239 F_3B 12 EB	115	150	8.3	2130	700 (2)[1]	830 (7)	40	23
84061	ICPX 76239 F_3B 17 EB	120	150	8.3	1920	550 (8)	780 (8)	48	21
	C 11 (control)[2]	123	140	10.6	1840	190(14)	1600 (1)	63	12
	PPE 50-12	116	140	8.5	1730	300(11)	1290 (4)	66	11
	1CP 10466	112	130	7.4	1730	280(12)	1360 (3)	56	6
	ICP 1903 (control)	120	140	7.5	1700	550 (7)	690(11)	49	20
	BDN 1 (control)[2]	113	110	10.5	1510	240(13)	1060 (5)	76	21
84062	(3193-12 x Prabhat)-2	99	100	7.2	1360	840 (1)	970 (6)	36	30
	ICP 1691[2]	117	130	8.1	1240	480 (9)	1400 (2)	57	12
84063	(3193-12 x Prabhat)-1	92	110	7.6	1150	650 (3)	750(10)	34	23
84064	ICPX 75560 E3 EB	99	110	7.9	1130	590 (5)	670(13)	36	27
84065	T 21 x *Atylosia scarabaeoides*	100	130	7.4	1110	690 (4)	760 (9)	40	19
	ICPX 75560 F_5 EB-B	98	90	6.2	1050	370(10)	530 (14)	46	25
	ICPX 77303 F_4 EB-BX	97	110	7.0	940	590 (5)	670 (12)	35	27
	SE	± 1.1	±5	±0.19	±139	±67	±80		
	Mean	109	124	8.0	1466	499	953		
	CV (%)	2	8	5	19	27	17		

1. Numbers in parentheses indicate rank within trial.
2. *Heliothis-susceptible* entries.

(Table 6) into our medium-duration multilocational trial.

Biological Nitrogen Fixation

Rhizobium Culture Collection

About 200 *Rhizobium* cultures have been freeze-dried this year. We supplied approximately 100 units of *Rhizobium* strains, as peat inoculants or agar slopes to the All India Coordinated Pulses Improvement Project (AICPIP) and other requesting scientists in India and elsewhere.

Screening *Rhizobium* Strains

Sixteen *Rhizobium* isolates from pigeonpea nodules collected from Gujarat and Maharashtra were screened for nodulating and nitrogen-fixing ability. The test cultivar, ICP 1-6, was inoculated with the test strains and grown in a sterile sand-vermiculite-grit mixture irrigated with a nitrogen-free nutrient solution in a greenhouse. Six weeks after sowing there were significant differences between *Rhizobium* isolates in nodulation parameters and plant dry matter. However, none of the isolates produced plants as large as those in a noninoculated control treatment supplied with 200 ppm nitrogen. Four of these *Rhizobium* isolates have been chosen for further evaluation in field trials.

Rhizobium Inoculation Trials in Farmers' Fields

Previous studies in farmers' fields had failed to detect responses of pigeonpea to inoculation even though soil nitrogen and rhizobial numbers were low (ICRISAT Annual Report 1982, pp. 144-145). This was suspected to be due to interacting mineral nutrient deficiencies as soil-available phosphorus levels were low. In 1982 we repeated these studies but included fertilizer treatments. Again, no significant responses to inoculation were found for nodulation, acetylene reductase activity, plant dry-matter yield, or grain yield. However, addition of 100 kg ha^{-1} nitrogen, 17 kg ha^{-1} phosphorus, and 1.2 kg ha^{-1} molybdenum significantly increased dry-matter yields at some sites. These studies highlight the need to identify and partition the effects of various environmental limitations on pigeonpea growth when interpreting inoculation responses.

Residual Effect of Pigeonpea

Previous studies suggested that the beneficial residual effect of pigeonpea on a subsequent maize crop was primarily due to fallen pigeonpea plant parts (ICRISAT Annual Report 1981, pp. 133-136). Thus we imposed treatments whereby pigeonpea cultivar ICP 1 was harvested at 130 days after sowing (DAS), at 260 DAS on plots kept litter-free, and at 260 DAS on plots where accumulated litter was incorporated into the topsoil after harvest (Fig. 10). In 1982, maize (Deccan Hybrid 101) was uniformly grown on all plots. There was no significant effect of litter on grain yield, above-ground dry matter, or uptake of nitrogen and phosphorus by the maize (Table

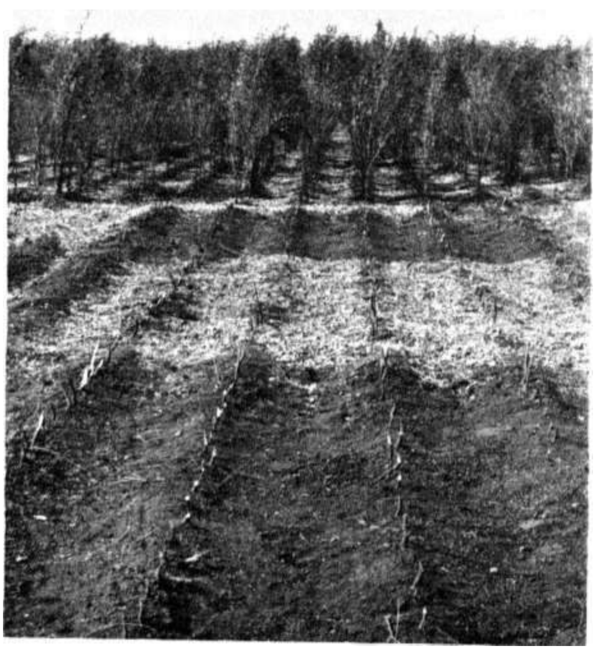


Figure 10. Pigeonpea trial after harvest showing (foreground) plots cleared of all litter and (center) plots with residual litter that will be incorporated into top soil, ICRISAT Center, 1984.

Table 7. Effect of pigeonpea grown for various periods with and without fallen plant parts on grain and above-ground dry-matter yields, and nitrogen (N) and phosphorus (P) uptake of maize grown in the following year on a Vertisol, ICRISAT Center, rainy season 1982.

	Maize (kg ha"^{1})			
Treatment	G**ain yield	Above-ground dry-matter	N uptake by tops	P uptake by tops
Harvested at 130 days	2360	6220	51.4	7.0
Harvested at 260 days, removed litter	1940	5320	43.0	6.2
Harvested at 260 days, left litter	1710	5130	38.5	5.9
SE	±109	±203	±1.52	±0.22
CV(%)	23	15	14	14

Table 8. Dry matter, N, and P contents of pigeonpea leaf litter in a Vertisol, ICRISAT Center, summer 1982.

Treatment	Dry matter (g)	N content(g)	P content (g)
Soil surface			
at day 0	39.7 (±0.33)*	0.67 (±0.010)	0.040
at day 73	27.9 (±1.71)	0.30 (±0.200)	0.020
Buried			
at day 0	36.3 (±2.36)	0.61 (±0.043)	0.034 (±0.0030)
at day 73	15.2 (±3.16)	0.26 (±0.053)	0.012 (±0.0030)

1. SE values shown in parentheses.

7). However, these values were significantly higher where pigeonpea had been harvested at 130 DAS. Further long-term experimentation is needed to understand why both negative and positive residual effects of pigeonpea can occur.

We studied the decomposition rate of pigeonpea leaf litter during summer 1982. Litter was placed in nylon bags which were either kept on the soil surface, or buried 10 cm deep. After 73 days in a Vertisol the litter had lost approximately half of its dry matter, nitrogen, and phosphorus, with the losses being greater in buried samples (Table 8).

Grain and Food Quality

Cooking Quality

We studied the effect of geographical locations on cooking quality of pigeonpea. Seven cultivars (ICPH 2, ICPH 5, BDN 1, BDN 2, AS 71-37, MAUL 175, and C 11) were grown (in two replications) at eight Indian locations (Coimbatore, Gulbarga, ICRISAT Center, Jabalpur, Jalna, Junagadh, Krishinagar, and Sardar) in the 1982 rainy season. Both replications were pooled before preparing dhal for analysis because only a limited quantity of seed was available. We soaked samples in water for 8 h, dried them at 60° C overnight, and then decorticated them in a barley pearler. The resulting dhal samples were analyzed for cooking time, water absorption, and texture. We estimated cooking time by cooking in an open vessel and determined dhal texture using a Instron food-testing machine. Preliminary results indicate that cooking quality characteristics did not show large differences between the cultivars grown at different locations.

Protein Quality

We determined the amino acid composition of 16 genotypes representing normal and high protein pigeonpea lines. Tryptophan content was also determined after alkaline hydrolysis. Protein content of these lines ranged from 22.7 to 30.2%, whereas sulfur-containing amino acids, methionine, and cystine varied from 2.25 to 2.80 g/100g protein. The correlation between methionine plus cystine and protein was negative but non-significant, indicating the possibility of increasing protein content without greatly affecting the quantity of sulfur-containing amino acids. The tryptophan content of these lines varied from 0.59 to 0.94 g/100g protein and a negative correlation of r=-0.60** was obtained between their protein and tryptophan contents.

We analyzed 3396 whole seed and dhal samples of breeding material for protein content. The protein content of 227 dhal samples, including high protein lines, varied from 18.6 to 31.5%, whereas the protein content of whole seed samples ranged from 14.6 to 23.5%. The protein content of 975 dhal samples of germplasm accessions varied from 16.1 to 29.5%. Methionine was estimated in 899 and tryptophan in 529 defatted dhal samples. Methionine contents ranged from 0.71 to 1.56 g/100g protein, whereas tryptophan ranged from 0.55 to 0.95 g/100g protein.

Breeding for Protein Content

We compared the amino acid profiles of the high protein lines derived from inter-generic crosses that we reported last year (ICRISAT Annual Report 1983, p. 171). The results indicated that the quantity of the important sulfur-containing amino acids methionine and half cystine was similar to that in the adapted cultivars Pant A2, T 21, Baigani, and 1CPL 270.

Sugar Analysis

Developing seed samples of BDN 1, Hy 3C, ICP 7035, ICP 6997, and ICP 11947 collected at 20, 25, 30, 35, and 40 DAF during the 1982 rainy season at ICRISAT Center were analyzed for their sugar content. Total soluble sugars were determined by a colorimetric method in freeze-dried samples. Using thin layer chromatography, we determined glucose, fructose, sucrose, raffinose, stachyose, and verbascose contents. Although the levels of these sugars did not vary greatly between the cultivars, remarkable differences were observed in the levels of these sugars at different stages of maturation (Table 9). The level of glucose + fructose decreased whereas that of sucrose increased as the seed matured. The flatulence-causing sugars raffinose and stachyose, present in very low concentration during the early stages of maturation, increased during the later stages. Another flatulence-causing sugar, verbascose, was not detected in the early stages of maturation, but a large amount of this sugar was present in the mature seed, showing that flatulence-causing sugars are accumulated during the later stages of seed maturation.

Table 9. Levels of soluble sugars at different stages of seed maturation (measured in DAF) of pigeonpea cultivar BDN 1, ICRISAT Center, rainy season 1982.

	Days after flowering (DAF)				
Constituent	20	25	30	35	40
Glucose + Fructose[1]	29.3	22.0	35.2	11.4	7.3
Sucrose[1]	34.2	46.1	40.0	33.8	32.7
Raffinose[1]	4.1	3.0	11.2	18.3	14.6
Stachyose[1]	2.7	2.1	4.6	17.0	14.8
Verbascose[1]	ND[3]	ND[3]	ND[3]	17.0	23.9
Total soluble sugar[2]	6.3	5.0	4.2	3.9	3.8

1. g/100 g soluble sugars.
2. g/100 g seed sample.
3. ND = Not detected.

Chemical Analysis of Podfly-Resistant and -Susceptible Lines

Tender pod walls of four podfly-resistant and -susceptible lines each grown in four replications were collected at ICRISAT Center during the rainy season 1983. Crude fiber (cellulose), acid-detergent fiber (cellulose + lignin), nitrogen fractions, soluble sugars, and phenolic compounds were analyzed in oven-dried (60°C) finely-ground samples. We estimated the lignin content by measuring the difference between crude fiber and acid-detergent fiber. No clear-cut difference in the levels of these constituents was observed between resistant and susceptible lines.

Plant Improvement

Short-Duration Pigeonpea

The area sown to short-duration pigeonpea continued to expand in northern India moving into some areas previously planted to long-duration pigeonpea. Short-duration pigeonpea is also showing potential to yield well in peninsular India and at our cooperative station in Bamako, Mali. Because this type of pigeonpea matures early, it generally has more flexibility to fit well into existing cropping patterns. Thus it has been grown in rotation with wheat in northern India and sown early as an intercrop with short-duration legumes such as mung bean and groundnut. Some lines have been shown to give excellent 2nd and 3rd crops. One such line is ICPL 87 which gave 5500 kg ha^{-1} from three harvests in 217 days (ICRISAT Annual Report 1983, pp. 171-172).

In 1984 ICPL 87, selected from the cross T 21 x JA 277, was identified by AICPIP and proposed for release in the Peninsular Zone of India. There was also a pre-release proposal for Maharashtra State submitted by Marathwada Agricultural University.

There is presently no pigeonpea cultivar in India like ICPL 87. This line is of medium height with determinate growth habit, and compared with most Indian cultivars produces large pods with large seeds. The pods have red stripes and the seeds are brown. It is tolerant to wilt. Although it matures after UPAS 120 and before T 21 it is generally considered too late for rotation with wheat in northern India. When allowed to mature fully it has consistently given high yields (Table 10). ICPL 87 is particularly useful for multiple harvesting as it has continued to remain green and productive after each of three pickings so long as there was sufficient available soil moisture.

As we reported last year (ICRISAT Annual Report 1983, pp. 172-175) the practice of sowing a pigeonpea/mung bean intercrop in April has produced good grain yields along with abundant wood for fuel. Pigeonpeas sown at that time usually start flowering when the temperatures are very high. These high temperatures may cause most flowers to drop, or completely suppress flowering so that there are no pods set until the temperatures drop in June end or July. Some of our extra-short-duration determinate lines,

Table 10. Comparison of pigeonpea lines ICPL 87 and UPAS 120 grain yields (kg ha^{-1}), Hisar, 1979-1983.

	Grain yield (kg ha^{-1})					
Lines	1979	1980	1981	1982	1983	Mean
ICPL 87	1930	3000	3030	3050	2370	2676
Control						
UPAS 120	1280	2140	2400	2150	1455[1]	1885
SE	±86	±110	±171	±139	±200	
CV (%)	20	10	11	8	26	

1. ICPL 4 used as control in 1983.

Table 11. Performance of some promising pigeonpea lines intercropped with mung bean, Hisar (sown in April), 1983.

				Yield (kg ha^{-1})					
					Pigeonpea grain				
Entry	Days to flowering	Plant height (cm)	100-seed mass (g)	Mung bean grain	Jul harvest	Nov harvest	Total	Total grain	Pigeonpea dried stalk
Determinate									
ICPL 87	76	275	11.6	820	0	3840	3840	4660	22800
ICPL 94	76	235	9.1	970	70	2800	2870	3840	15510
ICPL 148	78	235	9.5	520	40	2640	2680	3200	23730
ICPL 312	89	205	13.0	580	50	2110	2160	2740	15050
ICPL 289	88	185	10.8	590	120	1930	2050	2640	5790
ICPL 267	67	195	8.4	780	180	1600	1780	2560	7180
Control									
ICPL 4	78	175	6.4	380	280	1200	1480	1860	10420
SE	±2.2	±14	±0.30	±196	—	±237	—	—	±1205
Trial mean (n=13)	75	208	8.6	678	84	1970	2054	2732	13240
CV (%)	4	9	5	20	—	17	—	—	13
Indeterminate									
ICPL 161	191	292	9.0	570	0	2490	2490	3060	32180
ICPL 314	184	294	8.7	650	0	2280	2280	2930	18980
ICPL 189	186	303	8.2	830	0	2270	2270	3100	29170
ICPL 186	190	299	9.4	1020	0	2240	2240	3260	22920
Control									
T 21	191	286	6.7	700	0	1940	1940	2640	24770
SE	±2.1	±10.5	±0.20	±74	—	±133	—	—	±1564
Trial mean (n=14)	177	287	8.2	772	—	2013	2013	2785	19280
CV (%)	2	7	4	19	—	13	—	—	16

however, can flower and set pods under high temperatures and are capable of producing a crop in July followed by a 2nd crop in November (Table 11). The early flush of flowers and pods is usually heavily attacked by pod borers, so judicious use of insecticides will be essential to obtain maximum benefit from this system. In 1983 the total yield of grain and wood using this system was very high.

The normal-season trials sown in late June at Hisar also gave high yields (Tables 12 and 13). This was in spite of abnormally warm, dry weather, which caused excessive vegetative growth, higher-than-normal flower drop, and an unusually high incidence of insect damage. The damage caused by *Maruca testulalis* and *Cydia critica* sp was particularly severe in the extra-short duration lines (Table 12). Among the extra-short-duration lines ICPL 317 gave a high yield this year. ICPL 316 yielded as well as the control ICPL 4 (a line from Prabhat), had good seed size, and showed resistance or tolerance to wilt, phytophthora blight, and SM. It also performed well in the 1981 and 1982 trials at Hisar.

Medium-Duration Pigeonpea

At ICRISAT Center our major pigeonpea breeding activities continued to be with medium-duration types. During the year we made 102

Table 12. Performance of some promising extra-short duration, determinate pigeonpea lines sown in June, Hisar, 1983.

Lines	Days to flowering	Days to maturity	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha-')
ICPL 317	72	156	205	8.8	3110
ICPL 8306	73	151	215	7.6	2260
ICPL 287	72	165	180	. 8.4	1830
ICPL 316	70	164	150	9.0	1640
Control					
ICPL 4	77	136	135	6.3	1620
SE	±0.6	±2.5	±2.9	±0.20	±77
Trial mean (n=14)	74	152	180	8.2	1766
CV (%)	2	3	3	4	9

crosses, grew out 259 F_1s, more than 4700 single-plant progenies, 179 bulk populations, and tested 1245 advanced lines for yield. Work on this maturity group also continued to emphasize development of lines that resist pests, diseases, and abiotic factors that reduce yield. (Details appeared earlier in this report).

Long-Duration Pigeonpea

We continued to breed long-duration pigeonpea at Gwalior and to conduct trials at the Morena Center of Jawaharlal Nehru Krishi Vishwa Vidyalaya, 35 km north of Gwalior. We are emphasizing breeding long-duration lines resistant to wilt, sterility mosaic (SM), phytophthora blight, and podfly in order to stabilize crop yields. Based on good performance over a range of environments ICPL 366, a selection from the germplasm collection 1CP 7105 that is SM-and alternaria blight-resistant, and has bold seed, was entered in the Late-Maturity Arhar Coordinated Trial (ACT 3) of AICPIP. ICPL 84072, a selection from ICPX 74360 (ICP 7065 x ICP 7035) with resistance to all the three major diseases (wilt, SM, and phytophthora blight—P2 isolate), was included in both the All India Coordinated Late-Maturity Pigeonpea Sterility Mosaic Resistant Yield Trial (LPSRY) and the Late-Maturity Pigeonpea Wilt Resistant Yield Trial (LPWRY).

In our advanced lines yield trials three ICRISAT lines significantly outyielded the control variety Gwalior 3 at Morena and yielded well at Gwalior (Table 14). Also at Gwalior we had a severe frost that gave us an opportunity to select breeding lines with frost tolerance or resistance. Their reaction is being confirmed at Hisar.

Hybrids

New hybrids. We produced and tested 27 short-duration and 26 medium-duration hybrids using six male-sterile stocks and 28 pollen parents. One of our short-duration hybrids, ICPH 8, has significantly outyielded the widely-adopted cultivars UPAS 120 and T21 for 2 years (Table 15). This year we are producing enough seed of ICPH 8 in isolation for multilocational testing in 1985.

Conversion. Our source for the ms_1 male-sterile gene was named ICPP 1 by the ICRISAT Plant Material Release Committee. This source has been used to introduce male sterility by backcrosses into 12 lines that have either good combining ability and/or some other special characteristic, such as large seeds or disease re-

Table 13. Performance of some promising short-duration pigeonpea lines sown in June, Hisar, 1983.

Lines	Days to flowering	Days to maturity	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha^{-1})
ICPL 8311	80	159	216	9.8	2390
ICPL 289	75	152	182	10.2	2300
ICPL 8308	104	168	219	10.4	2110
ICPL 8309	78	155	215	10.2	1890
Control					
ICPL 4	75	139	204	6.2	1300
SE	±1.3	±2.5	±4.2	±0.3	±138
Trial mean (n=26)	83	159	201	9.37	1805
CV(%)	2	3	4	5	13
ICPL 84023	79	167	223	9.0	3010
ICPL 84026	79	157	215	8.6	2840
ICPL 84025	104	176	214	10.1	2460
ICPL 84022	91	173	195	12.2	2410
Control					
ICPL 87	105	180	219	11.2	2260
SE	±1.9	±3.6	±8.7	±0.36	±180
Trial mean (n=36)	87	166	207	9.13	1967
CV(%)	3	3	5	5	11
ICPL 84048	102	164	259	9.1	2750
ICPL 84045	95	165	267	11.1	2520
ICPL 84044	97	164	269	12.2	2550
Control					
UPAS 120	105	167	268	7.4	2360
SE	±1.7	±2.9	±9.2	±0.2	±176
Trial mean (n=30)	98	162	256	8.90	2075
CV(%)	3	3	6	4	15
ICPL 84052	94	166	261	10.1	3010
ICPL 84050	97	169	253	7.4	2780
ICPL 84051	95	160	259	9.8	2740
Control					
UPAS 120	107	169	261	7.3	2090
SE	±1.0	±2.0	±10.0	±0.2	±179
Trial mean (n=30)	103	169	257	8.97	2362
CV(%)	2	2	7	4	13

sistance. These male-sterile lines will be used to broaden the genetic base of female parents in our hybrid project, and will be made available to those breeders interested in producing hybrids.

Considering the need for disease-resistant male-sterile stocks in the production of disease-resistant hybrids, the progenies of wilt-resistant converted lines C 11, BDN 1, NP(WR)15, and

Table 14. Performance of promising pigeonpea lines in yield tests of long-duration, advanced lines, Gwalior[1] and Morena, rainy season 1983/84.

Entry	Days to flowering	Days to maturity	100-seed mass (g)	Grain yield (kg ha^{-1})		Mean
				Gwalior	Morena	
ICPL 354	148	255	8.3	2710(10)[2]	3120 (1)	2912
Control						
Gw 3	151	252	8.4	2730 (9)	2460(12)	2594
SE	±1.6	±1.5	±0.37	±306	±219	—
Trial mean (n=16)	149	253	8.6	2690	2580	2636
CV (%)	2	1	7	23	15	—
ICPL 83140	149	252	9.2	2570 (2)	3140 (2)	2853
ICPL 83143	152	251	8.5	2040(12)	3160 (1)	2601
Control						
Gw 3	148	256	8.5	2130 (9)	2370 (16)	2249
SE	±1.3	±1.2	±0.26	±277	±245	—
Trial mean (n=20)	150	252	8.8	2150	2600	2372
CV (%)	2	1	5	26	16	

1. Grain yield data only.
2. Figures in parentheses represent overall rank in trial.

Table 15. Performance of short-duration pigeonpea hybrid ICPH 8 grown in 1982 and 1983 at Hisar. Characters other than yield are only reported for 1983.

Entries	Days to flowering	Days to maturity	Plant height (cm)	Seeds pod^{-1}	100-seed mass (g)	Yield (kg ha^{-1})		
						1982	1983	Mean
ICPH 8	108	171	312	3.8	8.9	3900	3560	3730
Controls								
UPAS 120	106	173	274	3.5	7.8	2230	2660	2445
T 21	112	171	308	3.6	8.3	2930	2510	2720
H77-216	91	151	259	3.4	7.9	—	2170	—
SE	±0.8	±1.7	±8.5	±0.18	±0.15	±100	±176	
CV (%)	1	2	5	9	3	8	13	

ICP 3783 were screened for resistance in the ICRISAT wilt-sick nursery along with 65 selections from MS 3A. From all this material we found over 30 progenies that had less than 10% wilt. We will attempt to confirm the resistance of these lines in the coming year using sib seed. Nine male-sterile converted progenies of ICP 3783 were also found to be completely free from SM disease.

With the availability of disease-resistant male-sterile stocks we will be able to develop medium-duration wilt- and SM-resistant hybrids. To meet future needs we have identified more disease-resistant and agronomically-superior lines in different maturity groups for conversion.

Clonal propagation. During this year we demonstrated the ease with which pigeonpea cuttings can be used to propagate special material. We used pencil-thick pieces around 15 cm long, either grown dipped in a hormone solution, or dipped in a commercial hormone powder and planted in moist sand (Fig. 11). Our previous attempts using mist propagators had been plagued by the material rotting, probably because of excessive humidity. This procedure will permit production of genetically-uniform lines for special studies, e.g., on wilt resistance, and *Rhizobium* infection. Because there is approximately 20% outcrossing in pigeonpea it is difficult to produce genetically-uniform seed for such studies. In addition we have used it to maintain and propagate special material such as male- and female-sterile plants, tetraploids, and certain mutants with low fertility.

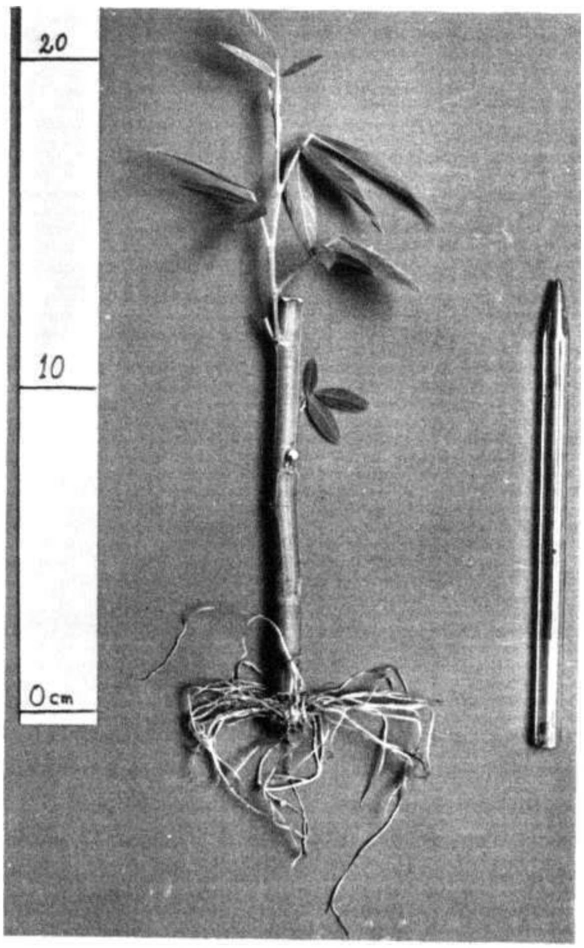


Figure 11. Rooted pigeonpea cutting grown with lower end dipped in aqueous hormone solution.

Cooperative Activities

International Trials

International Pigeonpea Wilt Nursery

For the past 2 seasons, we have been testing pigeonpea lines that have shown resistance to wilt at ICRISAT Center for their performance against wilt in Kenya and Malawi. This year we started an International Pigeonpea Wilt Nursery (IPWN) for uniform testing of 64 entries at Katumani, Kenya, and Bvumbwe, Malawi. The results are reported in ICRISAT Pulse Pathology Progress Report No. 43 available from the Pulses Improvement Program, ICRISAT.

During 1984 we distributed almost 200 yield trials to workers in 17 countries. The Pigeonpea Observation Nursery (PON) continued to be the single most-requested trial. When researchers grow this nursery its wide range of maturity, plant types, and resistances permits them to identify the class or type of material suited to their growing conditions. Results from PON have helped us identify which of our elite yield trials to send as a follow-up if requested. Short-duration trials accounted for almost 70% of the follow-up trials dispatched in 1984.

All India Coordinated Trials

Cooperation with AICPIP

All India Arhar (Pigeonpea) Varietal Trials. We continued to screen entries and breeding materials from AICPIP scientists for resistance to wilt, phytophthora blight, and SM, and communicated our results to them.

ICAR/ICRISAT disease nurseries. We operated four cooperative disease nurseries with AICPIP pathologists. These were: ICAR/ICRISAT Uniform Trials of Pigeonpea for Wilt Resistance (IIUTPWR), Sterility Mosaic Resistance (IIUTPSMR), Phytophthora Blight Resistance (IIUTPPBR), and Alternaria Blight Resistance (IIUTPABR). The results of the four

Table 16. Performance of ICRISAT pigeonpea entries in AH India Coordinated Pulses Improvement Project (AICPIP) ACT 2 trial at eight locations in Peninsular India, rainy season 1983.

Entries	Years tested	Days to flowering	Days to maturity	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha^{-1})
Hybrids						
ICPH 2	4	119	164	146	7.5	1760 (3)[1]
ICPH 7	2	134	167	154	8.1	1800 (2)
Lines						
ICPL 270	3	122	165	139	10.1	1810 (1)
ICPL 304	2	132	169	146	9.4	1670 (8)
ICPL 265	1	133	166	162	7.7	1610(12)
ICPL 295	1	131	168	147	8.6	1600 (14)
Controls						
BDN 1	—	122	159	131	9.5	1600 (13)
C 11	—	128	168	150	9.1	1720 (6)
Mean	—	—	—	—	—	1600

1. Figures in parentheses represent overall rank in trials.

nurseries were presented separately in ICRISAT Pulse Pathology Progress Reports Nos. 36,37,35, and 42, respectively (obtainable from the Pulses Improvement Program, ICRISAT).

We continued to cooperate with AICPIP. One quarter of the entries in the 1983/84 Arhar Coordinated Trials (ACT) were submitted by ICRISAT within the extra-extra-early trial (EXACT), nine in the extra-early trial (EACT), two in the early trial (ACT 1), seven in the medium-maturing trial (ACT 2), and four in the late-maturing trial (ACT 3).

In EACT ICPL 87, 151, 155, and 317 looked good, all being determinate and having good yield and seed size. ICPL 317 is particularly interesting because of its large white seed. In ACT 1 ICPL 189 generally yielded as well as the control cultivar T 21 but had larger seeds.

In ACT 2, the two hybrids ICPH 2 and ICPH 7 performed better than the control cultivars (Table 16). ICPL 270, an advanced breeding line, continued to perform well. On the basis of mean performance over eight locations in the Peninsular Zone, ICPL 270 ranked 1st followed by ICPH 2 and ICPH 7.

Workshops, Conferences, and Seminars

Pigeonpea Scientists' Meet

Over 50 pigeonpea scientists from Australia, Cape Verde Islands, India, Kenya, the Philippines, and Thailand attended a meet to see work on short-duration pigeonpea at HAU, Hisar, 18-20 October. There was a sharing of ideas among participants representing breeding, pathology, entomology, physiology, agronomy, and microbiology disciplines. Reports indicated a dramatic increase in the area being sown to short-duration pigeonpea a need for still earlier cultivars; the necessity of easier pest control to ensure early maturity and high yields; a need for short-duration pigeonpeas resistant to phytophthora blight and sterility mosaic, and an increasing interest in short-duration pigeonpea from countries outside India. Selections were made by the participants from ICRISAT material in the field.

Visiting scientists inspecting short-duration pigeonpea and making selections of ICRISAT material during meeting at Hisar, October 1984.

Consultants Workshop on Adaptation of Chickpea and Pigeonpea for Tolerance to Abiotic Stresses

This workshop was held at ICRISAT Center, 19-21 December to review the current knowledge on chickpea and pigeonpea tolerance to such abiotic stresses as water (drought and waterlogging), salinity, pH, and others, and to formulate a program of future work. Five consultants from four countries and ICRISAT staff participated.

The meeting found a need for a proper assessment of the magnitude, and timing of occurrence of different types of stresses, and the relative losses in yield that they induce in these two crops in different regions. Discussions on drought were around three major points: climatological quantification, crop management strategies in drought environments, and crop improvement for drought tolerance. Waterlogging, salinity, and low pH problems were discussed in depth, in terms of the relative merits of amelioration, or crop improvement strategies to cope with the problem.

It was apparent from the deliberations that very limited information is available on the response to drought and other stresses in both the crops, and on drought in pigeonpea in particular. Proceedings are in preparation and will be available from Information Services, ICRISAT.

Looking Ahead

We expect to provide short-duration lines suitable for early sowing intercropped in northwest India with short-duration legumes such as mung bean. We expect also to provide extra-short duration lines that can be sown in the same area as late as early August, yet be harvested by mid-November in time to plant wheat. With the stationing of a pigeonpea breeder at the Gwalior cooperative research center we will intensify our efforts to breed long-duration pigeonpeas with stable high yields. We will continue to cross the high-performance, resistant material we have bred in order to produce high-performance genotypes of all maturity groups with combined disease and insect resistances.

Work on determining optimum agronomic practices for multiple-harvest systems of early pigeonpeas will continue. Studies on drought, and interactions between drought and mineral nutrient stress will intensify. Screening for tolerance to salinity and waterlogging will continue. Investigations of possible annual characters in pigeonpea will be undertaken. Responses of pigeonpea to shading, particularly to determine reactions of different genotypes to intercropping, will be studied.

We will develop appropriate methodology to enable us to detect situations where pigeonpea is likely to respond to rhizobial inoculation. Methods for detecting differences between *Rhizobium* strains, and N-fixing ability in pigeonpea genotypes will be refined. Studies on the residual effects of pigeonpea will continue. An assessment will be made of the potential for mycorrhizal inoculation.

We expect the analyses of the pheromone and light trap data to increase our understanding of the factors that influence the seasonal populations of *Heliothis armigera.* Progress in host-plant resistance to both pod borer and podfly should soon make available genotypes that will ensure good yields under farmers' field conditions without excessive use of pesticides.

We will intensify our studies on the physiologic races of various pathogens. Purification of the sterility mosaic virus will be attempted. Epidemiological studies on wilt and phytophthora blight will continue. Work on fungus-nematode interaction will be initiated.

Publications

Institute Publications

Faris, D.G., and Scheming, J.F. 1984. Pigeonpea for West Africa: a pulse crop with great potential. Patancheru, A.P. 502 324, India: ICRISAT. 9 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Poisd' Angole: legumineuse a grand potentiel en Afrique de l'Ouest. Patancheru, A.P. 502 324, India: ICRISAT. 9 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Pulses Improvement Program. 1984. International Pigeonpea Newsletter no.3 (Faris, D.G., ed.). Patancheru, A.P. 502324, India: ICRISAT. 76 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 98 pp.

Rupela, O.P., Dart, P.J., Toomsan, B., Singh, D.V., Subramaniam, D., and Sharma, B.K. 1984. Facility for growing plants in test tubes at ICRISAT. Information Bulletin no. 18. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 8 pp.

Thompson, J.A. 1984. Production and quality control of carrier-based legume inoculants. Information Bulletin no. 17. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 37 pp.

Journal Articles

Kannaiyan, J., and Nene, Y.L. 1984. Efficacy of Metalaxyl for control of phytophthora blight of pigeonpea. Indian Phytopathology 37:506-510.

Kannaiyan, J., Nene, Y.L., and Bisht, V.S. 1984. Ridomil application methods for the control of pigeonpea phytophthora blight. Indian Phytopathology 37:384. (Abstract.)

Kannaiyan, J., Nene, Y.L., Reddy, M.V., Ryan, J.G., and Raju, T.N. 1984. Prevalence of pigeonpea diseases and associated crop losses in Asia, Africa and the Americas. Tropical Pest Management 30(1):62-71.

Kumar, P.S., Subrahmanyam, N.C., and Faris, D.G. 1984. Nucleolar variation in a pigeonpea intergeneric hybrid: evidence for allosyndetic recombination. Canadian Journal of Genetics and Cytology 26:499-505.

Kumar Rao, J.V.D.K., Dart, P.J., and Usha Kiran, M. 1984. *Rhizobium* induced leaf-roll in pigeonpea (*Cajanus cajan* (L.) Millsp.). Soil Biology and Biochemistry 16:89-91.

Reddy, M.V., Kannaiyan, J., and Nene, Y.L. 1984. Increased susceptibility of SM infected pigeonpeas to powdery mildew. International Journal of Tropical Plant Disease 2:35-40.

Saxena, K.B., and Sharma, D. 1983. Early generation testing in pigeonpea. Tropical Plant Science Research 1(4):309-313.

Sharma, D., and Sharma, K.B. 1983. Genetic analysis of some leaf characteristics of *Cajanus cajan* (L.) Millsp. Field Crops Research 7:257-263.

Singh, U. 1984. The inhibition of digestive enzymes by polyphenols of chickpea *(Cicer arietinum* L.) and pigeonpea (*Cajanus cajan* L. Millsp.). Nutrition Reports International 29:745-753.

Singh, U., Jain, K.C., Jambunathan, R., and Paris, D.G. 1984. Nutritional quality of vegetable pigeonpeas *(Cajanus cajan* [L.] Millsp.). Mineral and trace elements. Journal of Food Science 49:645-646.

Singh, U., Jain, K.C., Jambunathan, R., and Faris, D.G. 1984. Nutritional quality of vegetable pigeonpeas *(Cajanus cajan* [L.] Millsp.). Dry matter accumulation, carbohydrates and proteins. Journal of Food Science 49:799-802.

Singh, U., Sahrawat, K.L., Jambunathan, R., and Burford, J.R. 1984. The use of hydrogen peroxide for the digestion and determination of total nitrogen in chickpea *(Cicer arietinum* L.) and pigeonpea *(Cajanus cajan* L). Journal of the Science of Food and Agriculture 35:640-646.

Conference Paper

Faris, D.G. 1984. ICRISAT's research on pigeonpea. Pages 17-20 in Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

GROUNDNUT

Contents

Cover photo: Wild *Arachis* species growing in concrete ring cultures, ICRISAT Center, 1984.

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GROUNDNUT

Seventy percent of the world's groundnuts, more than any other legume, are produced in the semi-arid tropics (SAT). Containing approximately 25% protein and 50% edible oil, groundnuts are important to SAT farmers as food and for cash. The haulms remaining after the pods are removed, are a valuable, nutritious animal feed. The average yield of groundnut in the SAT remains extremely low (around 800 kg ha^{-1} dried pods) and fluctuates widely due to unreliable rainfall. Disease and insect pest attack also severely reduce yields.

During the 1983/84 postrainy and 1984 rainy seasons, we continued research into disease and insect pest problems, drought and nutrient stresses. We also studied interactions between the various stress factors. Our continuing improvement strategy is to use the genetic diversity in groundnut and its wild relatives to breed for stable resistance or tolerance to the major yield reducers.

Table 1. Groundnut lines identified as tolerant or susceptible in drought-screening experiments, 1CRISAT Center, postrainy seasons 1981-83.

Genotype	Reaction to drought
GNP 35	Tolerant
ICG 1660	Tolerant
ICG 3386	Tolerant
ICG 3736	Tolerant
ICG 296	Tolerant
ICG 405	Tolerant
ICG 1697	Tolerant
ICG 4790	Tolerant
ICG 4747	Tolerant
ICG 6997	Tolerant
ICG 2960	Tolerant
ICG 3301	Tolerant
ICG 4544	Tolerant
ICG 4728	Tolerant
ICG 3657	Tolerant
ICG 6256	Susceptible
ICG 5274	Susceptible
ICG 3073	Susceptible
ICG 3500	Susceptible

Physical Stresses

Drought

Screening Genotypes

During the 1983/84 postrainy season 477 genotypes consisting of 295 breeding lines and 182 germplasm lines were screened for their response to three drought patterns (mid-season stress, terminal stress, and long-duration stress). Lines identified in earlier drought screening were also included. Lines found to be either susceptible or tolerant/resistant in three seasons are listed in Table 1.

Drought Physiology

Last year (ICRISAT Annual Report 1983, p. 184) we reported an experiment where 25 genotypes with differing drought responses, as characterized in the drought-screening process, were tested in 96 different irrigation treatments that varied the intensity (8 levels), duration (both single and multiple), and timing of drought periods (12 patterns, P1-P12, shown in Figure 1). We made further analyses of this data set to investigate the interactions of genotypes with droughts of different kinds.

We expressed the intensity of drought as the percentage water deficit (I) calculated using the formula :

$$I = \frac{(E-W)}{E} \times 100$$

where E = cumulative water evaporation, and

W = cumulative water applied during the phase of deficit irrigation

Except where plant mortality occurred as a result of prolonged drought, the relationship

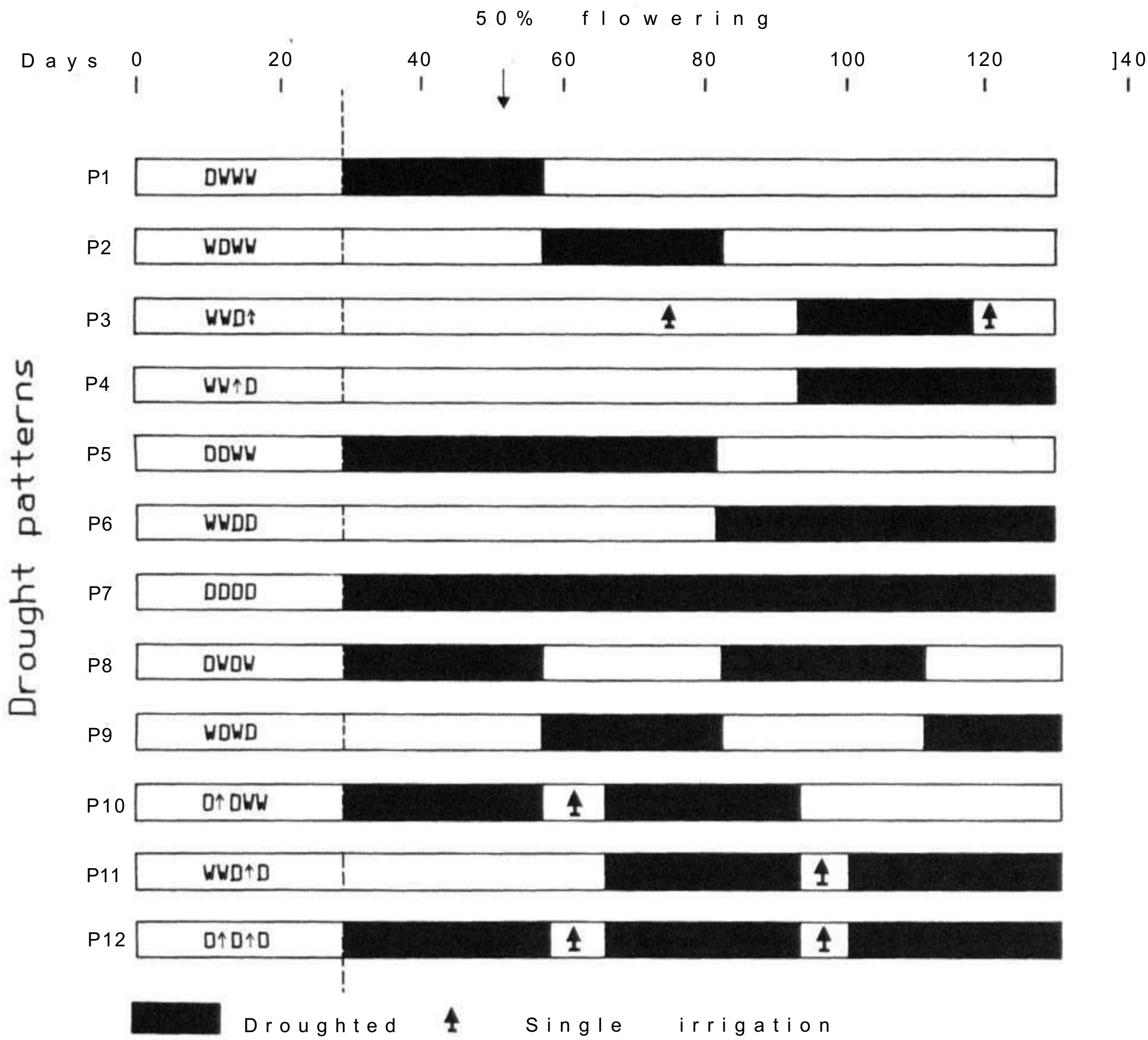


Figure 1. Duration and timing of drought periods in groundnut stress trial (12 drought patterns, P1 -P12), ICRISAT Center, postrainy season 1983/84.

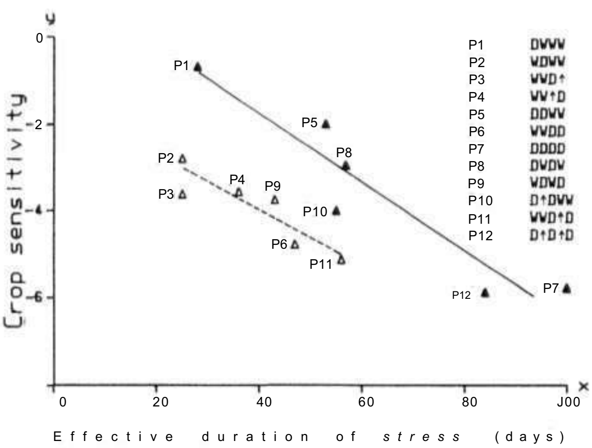
between intensity of stress and yield was always linear. The slope of this regression was therefore the sensitivity of the genotype, or group of genotypes, to that particular pattern of drought.

We then investigated the main effects of the duration and timing of droughts on the mean sensitivity of this group of genotypes, by examining the sensitivity to increasing intensity for the 12 drought patterns. For droughts lasting about 30 days, the later in the growing season these occurred, the greater the resulting yield loss from a given intensity of drought. A similar effect occurred when the droughts lasted longer. Because the yield loss was varied by the timing of the drought, the direct relationship between sensitivity and drought duration was relatively poor ($r^2 = 0.43$).

However, the effect of drought duration on sensitivity was found to be very much better correlated for two groups of treatments: when the crops had been droughted in the early pre-flowering phase ($r^2 = 0.85$), and when the crops had been well-irrigated for that phase (r^2 = 0.25). The drought sensitivity was greatest for a given drought duration when the crop had initially been well-irrigated (Fig.2). If the conditions during the preflowering phase, and the drought duration were considered, we could account for 85% of the variation in sensitivity.

We found that the genotype's yield potential could have a large influence on its sensitivity to certain patterns of drought. In some drought patterns (Fig.3) the yield potential accounted for 95% of the variation in drought sensitivity, while in others yield potential was not related to drought sensitivity (Fig.4).

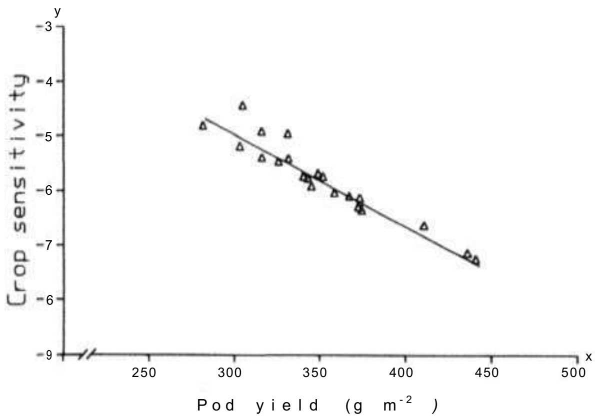
Generally, there was a pattern in the relationship between yield potential and drought sensitivity. Where drought occurred over the final growth phases (see Fig. 1), the yield potential was very well-related to drought sensitivity, suggesting that resistance to end-of-season droughts will not be achieved in lines with high yield potential. However, as the period between the relief of stress by irrigation and harvest increased, the drought sensitivity was generally



▲ y = 1.24 -0.076x, rse = 0.82
r = 0.93, *P* < 0.01

△ y = -1.53 -0.62x, rse = 0.43
r = 0.89, *P* < 0.02.

Figure 2. Effect of timing, intensity, and duration of drought stress (days) on groundnut crop sensitivity measured as pod dry mass g m^{-2} unit^{-1} water deficit for 12 drought patterns (P1-P12), ICRISAT Center, postrainy season 1983/84.



△ y = 0.14 - 0.016x, rse = 0.34
r = 0.83, P< 0.01.

Figure 3. Relationship between groundnut yield potential measured as pod yield (g nr^2) and crop sensitivity under nonstressed conditions (pod dry mass g nr^2 unit"^{1} water deficit) in a long-term drought treatment, ICRISAT Center, postrainy season 1983/84.

less related to yield potential It would be possible to select high-yielding lines resistant to early patterns of drought. We are considering the implications of these responses to crop improvement.

In another experiment during the 1983/84 postrainy season we examined in detail the geno-

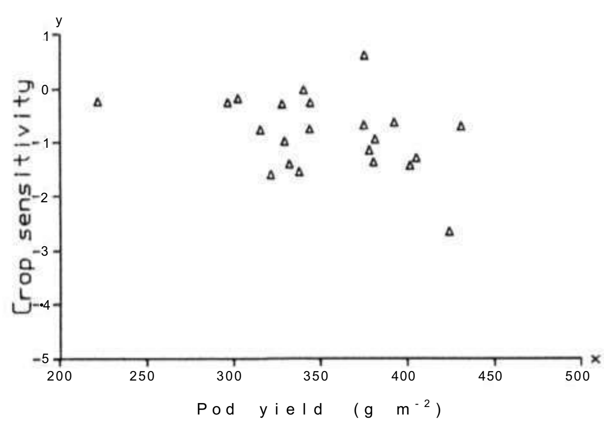


Figure 4. Relationship between groundnut yield potential measured as pod yield (g m^{-2}) under non-stressed conditions and crop sensitivity (pod dry mass g nr^2 unit^{-1} water deficit) following the relief by irrigation of mid-season drought, ICRISAT Center, postrainy season 1983/84.

typic variation in the recovery response from mid-season stress. We subjected 144 germplasm lines to mid-season stress from 53 to 92 days after sowing (DAS), after which stress was relieved by irrigation. Significant genotypic differences in pod establishment were observed after the stressed plants were irrigated (Fig. 5).

We completed analysis of a collaborative experiment with an ODA-funded project at the University of Nottingham, UK, during the 1981/82 postrainy season. The experiment was designed to see how sowing density can be used to adjust the balance between the soil supply and the atmospheric demand for water. Four populations of groundnut (TMV 2) were maintained on stored water from 44 DAS until final harvest at 97 DAS. The populations established were 22.9 (A), 11.4 (B), 6.6 (C), and 0.6 (D) plants m^2.

Shoot and pod masses were measured five times in the season by standard growth analysis techniques, and root masses in the A, B, and C populations were measured using cubic corers pushed into the sides of trenches across adjacent rows. We estimated soil-water content using a neutron probe every 5 days between 50 and 95 DAS, and continuously recorded light interception using tube solarimeters.

Dry matter and water use. Because plant growth is closely related to transpiration, the productivity of a crop is often expressed in terms of its water-use ratio (WUR), i.e., the ratio of dry mass to total water use). In Figure 6 the slope of the regression shows the WUR for shoots, averaged over the four populations at final harvest. The figure also shows intermediate harvests in the A, B, and C populations, but in the D population only the final harvest is included because absolute values were small. The average WUR was 1.58 mg g^{-1}. For most of the season, the A population consistently produced more dry mass of shoots $unit^{-1}$ of water transpired than the other populations. The correlation between shoot dry matter and transpiration was relatively poor when averaged over a range of populations. However, when roots were included in the dry-matter component (Fig. 7), the relation was linear, both during the season and as an average. The WUR was calculated for total dry mass of shoots and roots in the A, B, and C populations, but population D was excluded because roots were not measured. The WUR for total dry matter (TDM) was 3.33 mg g^{-1}.

Over the season, the mean vapor-concentration difference between leaf and air increased from 14 to 20 g m^{-2}.

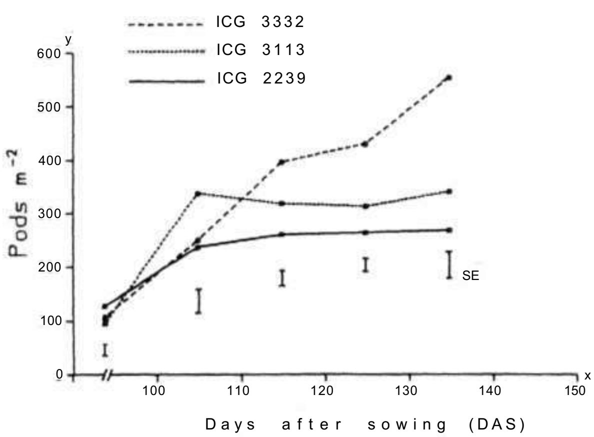
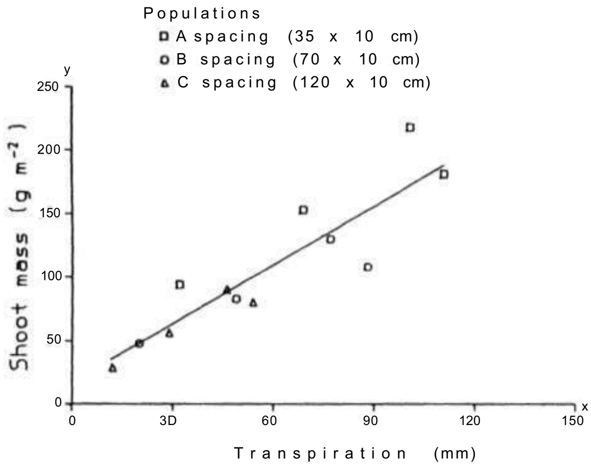


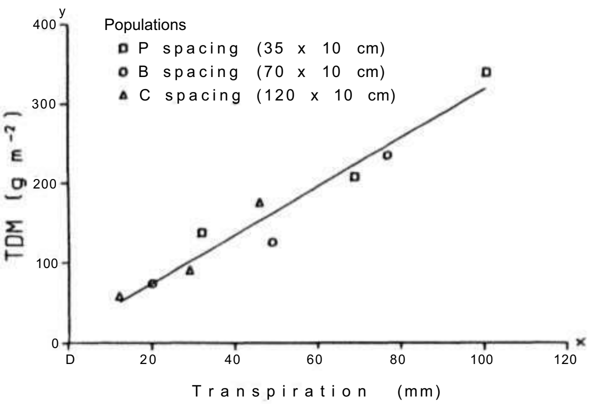
Figure 5. Pod initiation (pods m^{-2}) following the relief by irrigation of drought stress at 95 DAS for three groundnut genotypes, ICG 3332, ICG 3113, and ICG 2239, ICRISAT Center, postrainy season 1983/84.



y = 15.8 + 1.57x, rse = 25

r = 0.82, P < 0.01.

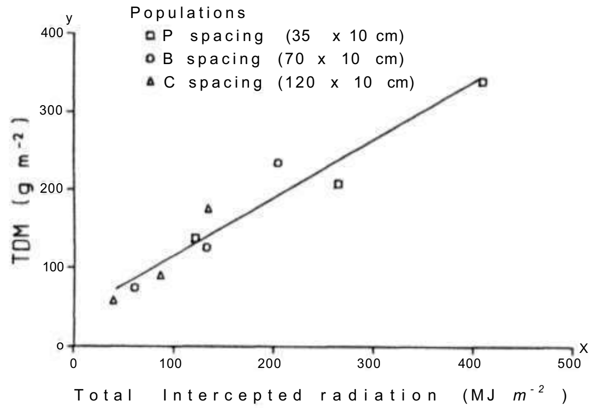
Figure 6. Relationship between transpiration (mm) and shoot mass (g m^{-2}) in groundnuts at three plant populations, ICRISAT Center, postrainy season 1983/84.



$y = 15.3 + 3.00x$, rse = 22

$r = 0.82$, $P < 0.01$.

Figure 7. Relationship between transpiration (mm) and total dry matter (TDM, g m^{-2}) in groundnuts at three plant populations, ICRISAT Center, postrainy season 1981/82.

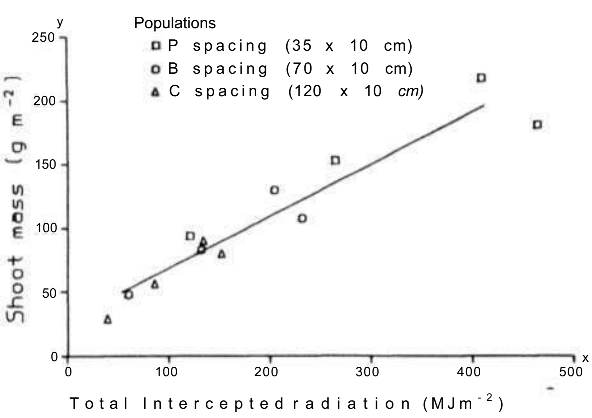


$y = 40.4 + 0.74x$, rse = 25

$r = 0.93$, $P < 0.01$.

Figure 9. Relationship between total intercepted radiation (MJ m~^{2}) and total dry matter (TDM, g nr^{2}) in groundnuts at three plant populations, ICRISAT Center, postrainy season 1981/82.

Dry matter and light interception. Figure 8 shows the relation between accumulated dry mass of shoots between 47 and 90 DAS, and the amount of light intercepted over the same period. The slope of the line is the light-use ratio (LUR). During the season, the slope of the regression was again greater than that at final harvest (LUR = 0.42 g MJ^{-1}). In Figure 9 the relationship is shown for TDM and, as with



$y = 29.4 + 0.39x$, rse = 18

$r = 0.9$, $P < 0.01$.

Figure 8. Relationship between total intercepted radiation (MJ m^{-2}) and shoot mass (gm^{-2}) in groundnuts at three plant populations, ICRISAT Center, postrainy season 1981/82.

transpiration, the LUR for final harvest closely matched the constant of proportionality over the whole season. The slope of the line was 1.01 g MJ^{-1}. The last two harvests of population A fell below the line of average LUR; the increment in TDM over this period was less than that predicted from the LUR established earlier in the season.

This study provides further experimental evidence that dry matter is a predictable function of transpired water, and of light interception when water is not limiting. The relationship was independent of sowing density. The analysis is unusual because it includes the contribution of roots to the TDM. When they were included, a good correlation existed between TDM and transpiration over a range of populations and seasonal transpiration. The correlation was maintained because the increased allocation of assimilate to the roots as drought developed largely compensated for the curtailing of shoot growth, as can be seen by comparing Figures 7 and 8.

In the field, the most important influence on WUR is the gradient of vapor concentration (X), between that in the leaf (X_1) and that in the air (X_2). WUR is linearly related to the reciprocal of X when other factors remain constant. A change in either X_1 or X_2 can influence X. In this study, X was probably independent of population because plots were too small to have systematic differences in air temperature or vapor content. There were differences in leaf temperature (and therefore X) between populations as drought stress developed in the denser stands. However, these differences were evident during the middle of the day when transpiration and assimilation rates were low. Changes in X are unlikely to have greatly influenced the absolute values of WUR. Variations in WUR between crops are more likely to be caused by differences in the balance between the supply of soil water and the atmospheric demand for transpiration.

Figure 10 compares seasonal transpiration with accumulated light interception, and illustrates the seasonal influence of drought on population A. For populations B and C, transpiration increased linearly with intercepted radiation at 0.37 mm MJ^{-1}, Because drought was never severe, transpiration (and therefore dry matter) was able to keep pace with light interception. Population A, however, behaved differently; the slope of the relation was only 0.23 mm MJ^{-1}. Even early in the season the daily uptake of water was insufficient to sustain the evaporative demand of the canopy in this population.

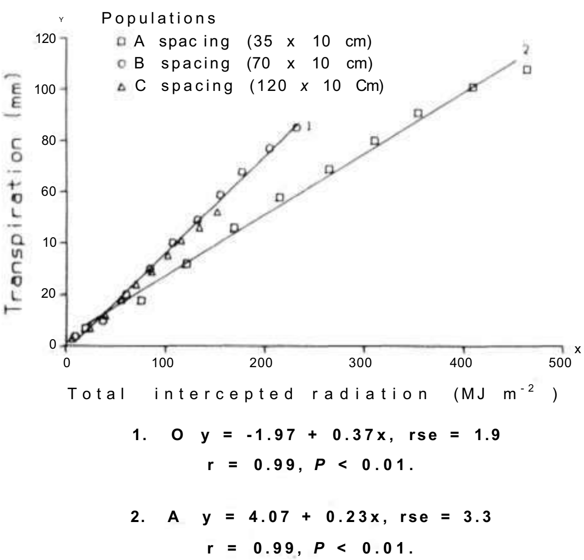


Figure 10. Relationship between total intercepted radiation ($MJ\ m^{-2}$) and transpiration (mm) in groundnuts at three plant populations, ICRISAT Center, post rainy season 1981/82.

Biotic Stresses

Diseases

The most serious diseases of groundnut on a worldwide basis are rust, caused by *Puccinia arachidis,* early leaf spot, caused by *Cercospora arachidicola,* and late leaf spot, caused by *Cercosporidium personatum.* Individually, each of these diseases can reduce yields by more than 50%; when they occur together, as they often do, losses can be even greater. The aflatoxin problem is also worldwide. Virus diseases can seriously damage groundnuts but, except for peanut mottle virus (PMV), they tend to be restricted in distribution. However, the recently-described peanut stripe virus disease (PStV) also appears to be widely-distributed, and merits concern.

Bacterial wilt, caused by *Pseudomonas solanacearum* is important in regions of east Asia, southern Africa, and parts of North America, but is apparently absent from many other important groundnut-growing regions. Nematode diseases are not considered important globally, but significantly damage groundnuts in restricted areas and may be linked to pod and root rots.

Research at ICRISAT Center has been largely determined by the occurrence and severity of particular diseases in India with priority given to work on foliar diseases, pod rots, aflatoxin contamination, and virus diseases.

Foliar Fungal Diseases

Resistance screening. In the 1984 rainy season, 1600 germplasm accessions received preliminary screening for resistance to rust. We selected 49 accessions that rated between 2 and 7 on a 9-point disease scale for advanced screening for resistance to rust and leaf spots in the 1985 rainy season.

Yield losses in 1984. Foliar disease development was delayed in the 1984 rainy season because of very dry weather in August. Short-season cultivars escaped severe attack, and damage to susceptible long-season cultivars was much lower than in normal years. The foliar diseases-susceptible cultivar ICGS 11 in a fungicide evaluation trial at ICRISAT Center yielded 2756 kg dry pods ha^{-1} under the most effective fungicide treatment, and 2163 kg ha^{-1} without fungicide, reflecting a yield loss from foliar diseases of 27%. We normally expect losses in the region of 70%.

Resistance breeding. We continued to advance progenies without selection in the 1983/84 postrainy season. During the 1984 rainy season they were selected under the high levels of rust and late leaf spot disease pressure that developed rapidly once the dry spell in August was over. New crosses, involving resistant, stable, tetraploid, interspecific hybrids, and breeding lines, were made to combine disease resistance with desirable agronomic traits.

Resistance selections yield trials. Breeding lines in different generations with resistance to rust and/or late leaf spot, were evaluated under both high- input (60 kg P_2O_s ha^{-1}, irrigation, and insecticides when required) and low-input (20 kg P_2O_5 ha^{-1}, rainfed, without insecticides) conditions. The controls in these experiments were released, disease-susceptible cultivars, and resistant parents. Trials were carried out in the 1983/84 postrainy and the 1984 rainy seasons. In the postrainy season foliar diseases are usually negligible because of the dry conditions and the yield potential of cultivars is expressed, while in the rainy season, disease pressure is usually associated with high yield losses of up to 70% in susceptible cultivars. In the 1984 rainy season however, because of the dry August, foliar diseases developed slowly and early-maturing cultivars such as JL 24 that matured just after the rains resumed, were only slightly affected and yielded more pods and haulms than usual (Table 2). Yield data are presented in Tables 2-7, and show the potential of some of the resistant hybrids under both rainfed and irrigated conditions at ICRISAT Center and Bhavanisagar.

Economics of resistance. We started on-farm trials in collaboration with ICRISAT econo-

Table 2. Performance of some F_{10} rust- and/or late leaf spot-resistant groundnut selections, ICRISAT Center, rainy season 1984.

	Yields (kg ha^{-1})		Disease reaction[1]	
Pedigree	Pods	Haulms	Rust	Late leaf spot
(NC Ac 2731 x PI 259747)F_{10} B	7180	3890	3	8
(Florigiant x Krap.St.No.I6)F_{10} B	6990	5900	2	7
(NC Ac 1107 x NC Ac 17090)F_{10} B	6860	4650	4	7
(NC Ac 1107 x NC Ac 17090)F_{10} B	6690	4380	3	7
(NC Ac 2768 x NC Ac 17090)F_{10} B	6490	5560	4	5
Controls				
NC Ac I7090[2]	6740	4930	2	6
ICGS IP	5970	4380	2	6
Robut 33-1[3]	5280	3750	9	9
JL 24[3]	4640	4170	9	9
SE	±401	±517	±0.6	±0.4
Trial mean	5491	3920	4.3	7.3
CV (%)	13	23	24.7	10.0

1. Field disease scored on a 1-9 scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.
2. Rust-and late leaf spot-resistant parent.
3. Foliar diseases-susceptible cultivars.

Table 3. Performance of some F_8 rust- and/or late leaf spot-resistant groundnut selections, ICRISAT Center, rainy season 1984.

	Yield (kg ha^{-1})		Disease reaction[1]	
Pedigree	Pods	Haulms	Rust	Late leaf spot
(Goldin 1 x PI 405132)F_8B	6780	5900	3	5
(Goldin 1 x PI 405132) F_8 B	6630	4240	2	4
(Manfredi « PI 405132)F_8 B	6280	6040	2	6
(Makulu Red x DHT 200)F_8 B	6170	4650	2	4
(72 R x 2-5) x PI 407454)F_8 B	6080	6700	2	4
Controls				
NC Ac 17090[2]	6080	5070	3	5
ICGS 11[3]	6190	2710	8	9
Robut 33-1[3]	5530	3330	8	9
JL 24[3]	4820	3190	8	9
SE	±282	±280	±0.3	±0.3
Trial mean	5590	4410	4.1	6.0
CV(%)	9	11	12.1	9.0

1. Field disease scored on a 1-9 scale, where 1 = no disease, and 9 = 50 - 100% foliage destroyed.
2. Rust- and late leaf spot-resistant parent. 3. Foliar diseases-susceptible cultivars.

Table 4. Performance of top ten entries in the groundnut multilocational foliar diseases resistance varietal trial, ICRISAT Center and Bhavanisagar, rainy season 1984.

ICRISAT Center				Bhavanisagar	
		Disease reaction[1]			
Pedigree	Yield (kg ha^{-1})	Rust	Late leaf spot	Pedigree	Yield (kg ha^{-1})
Ah 65 x NC Ac 17090) F_{11} B	7330	2	8	MGS 8 x EC 76446(292)	3710
(EC 76446(292) x Robut 33-1) F_8 B	7150	3	8	MH 1 x NC Ac 17090	3600
(NC Ac 400 x EC 76446(292) F_{12} B	7130	3	9	Robut 33-1 x EC 76446(292)	3430
(Robut 33-1 x EC 76446(292) F_8 B	7010	3	7	NC Ac 1107 x NC Ac 17090	3040
(RMP 91 x DHT 200) F_9 B	6890	3	8	TG 14 x NC Ac 17090	3030
(Florigiant x Krap. St. No. 16) F_{10} B	6850	3	8	NC Ac 400 x EC 76446(292)	2970
(GAUG 1 x EC 76446(292) F_{12} B	6740	2	9	Robut 33-1 x DHT 200	2850
(MGS 8 x EC 76446(292) F_{10} B	6690	2	7	RMP 91 x DHT 200	2690
(NC Ac 2564 x NC Ac 17090) F_9 B	6650	3	8	Ah 65 x NC Ac 17090	2670
(NC Ac 400 x EC 76446(292) F_{12} B	6610	2	9	MGS 9 x EC 76446(292)	2630
Controls				Controls	
NC Ac 17090[2]	6580	2	7	NC Ac 17090[2]	2650
ICGS 11[3]	5810	9	9	ICGS 11[3]	1510
Robut 33-1[3]	5750	9	9	Robut 33-1[3]	1460
JL 24[3]	4440	9	9	JL 24[3]	1510
SE	±305	±0.3	±0.3	SE	±268
Trial mean	5970	3.4	8.3	Trial mean	2230
CV(%)	9	17	7	CV (%)	21

1. Field disease scored on a 1-9 scale, where 1 = no diseases and 9 = 50-100% foliage destroyed.
2. Foliar diseases-resistant parent. 3. Foliar diseases-susceptible cultivars.

Table 5. Pod yield (kg ha^{-1}) of some rust- and/or late leaf spot-resistant groundnut selections, ICRISAT Center, postrainy season 1983/84.

Pedigree	Pod yield (kghas^{-1})
F_6 trial	
(JH 60 x PI 259747) x NC Ac 17133(RF)	7270
(JH 60 x PI 259747) x NC Ac 17133(RF)	7020
Controls	
NC Ac 17090[1]	6990
Robut 33-1[2]	6190
ICGS 11[2]	5940
SE	±366
Trial mean	6020
CV (%)	6
F_{10} trial	
Comet x NC Ac 17090	8060
G 37 x EC 76446 (292)	7560
Controls	
NC Ac 17090[1]	7540
Robut 33-1[2]	6130
JL 24[2]	5100
SE	±242
Trial mean	6400
CV(%)	7

Pedigree	Pod yield (kg ha^{-1})
F_{11} trial	
GAUG 1 x EC 76446 (292)	8320
JH 60 x PI 259747	7890
AH 32 x NC Ac 17090	7860
Controls	
NC Ac 17090[1]	7750
Robut 33-1[2]	6630
JL 24[2]	6610
SE	±322
Trial mean	6620
CV (%)	8
MLYT[3]	
NC Ac 2190 x NC Ac 17090	8330
SM 1 x EC 76446 (292)	8170
AH 6279 x PI 259747	7810
Controls	
NC Ac 17090[1]	7780
Robut 33-1[2]	6260
JL 24[2]	5040
SE	±229
Trial mean	6260
CV (%)	6

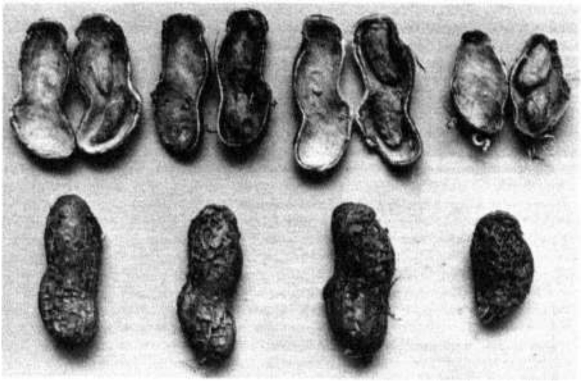
1. Foliar diseases-resistant parent.
2. Foliar diseases-susceptible cultivars.
3. MLYT = Multinational Yield Trial.

mists in the 1984 rainy season to determine the economic merit of using resistant cultivars compared with growing susceptible cultivars protected by fungicides. Severe drought caused crop failure in four of the five farmers' fields, and levels of rust and leaf spot diseases were lower than usual. Yield data from the one farmer's crop that gave reasonable yields, and from the companion trial at ICRISAT Center are given in Table 8. Information on acceptability of produce in the market is being collected. Economic analyses will be made after several more seasons' results are obtained.

Soilborne Fungal Diseases

Pod Rots

Resistance screening. Pod rot incidence was low in the 1983/84 postrainy season but lines previously identified as resistant had significantly less pod rot than control cultivars. We observed interactions between drought stress during pod maturation and pod rot severity in 36 genotypes grown under line-source irrigation. We are investigating the creation of artificial drought stress as a means of enhancing pod rot attack, to permit more effective screening of



Groundnut pods showing internal (above) and external (below) symptoms of pod rot. Infection by the causal fungi results in shrivelled seeds or empty pods when seeds are killed before they mature.

germplasm accessions for resistance to this disease.

The Aflatoxin Problem

Resistance screening. Eight genotypes previously found to have seed resistant to invasion by *Aspergillus flavus* were further tested using techniques reported earlier (ICRISAT Annual Report 1979/80, pp. 155-156). Resistance was confirmed in seed from the 1983/84 and 1984 seasons' crops.

Breeding for seed resistance to *A. flavus.* During the 1983/84 postrainy season we yield-tested 57 breeding lines, and a further 126 in the 1984 rainy season. The lines were derived from crosses involving such dry seed-resistant source lines as PI 337394 F, J 11, and UF 71513-1. We also conducted rainy-season trials at Anantapur, Bhavanisagar, Dharwad, and Hisar, in India. In the postrainy-season trials at ICRISAT Center we selected six breeding lines (Table 9) that combined high levels of resistance to seed colonization with good yield levels. One line was much more resistant than the most-resistant control and yielded 8% more than the highest-yielding control. These lines were advanced to multilocational testing for yield and adaptation in the rainy season (Table 10). Of the 88 breeding lines tested across locations in two trials during the 1984 rainy season, 19 were selected for their superior performance. The best breeding lines in the two trials showed 19.3 and 24% higher pod yield than the best control. The entries are now being screened for dry-seed resistance across locations.

Table 6. Pod yields (kg ha^{-1}) of some rust- and late leaf spot disease- resistant groundnut lines in rainfed trials, ICRISAT Center, rainy season 1984.

Pedigree	Pod yield (kg ha^{-1})
Virginia bunch-selections from interspecific derivatives	
CS-6/2-B_1-B_1B_1	1960
CS-46-B_3-B_3-B_1	1900
CS-22/2-B_2-B_1-B_1	1740
2024-B_3-B_1-B_1	1540
T-3-B_1-B_1-B_1	1500
Controls	
NC Ac 17090[1]	1290
ICGS 11[2]	1170
Robut 33-1[2]	1040
JL 24[2]	560
Si-	±127
Trial mean	1110
CV (%)	20
Multilocational trial, ICRISAT Center	
(Makulu Red x DHT 200)F_8 B	2170
(Comet x NC Ac 17090)F_{11}B	2060
(Ah 32 x NC Ac 17()90)F_{11} B	2010
(Argentine x PI 259747)F_{11} B	1990
(M 145 x PI 259747)F_{12} B	1980
Controls	
NC Ac 17090[1]	1290
ICGS 11[2]	1290
Robut 33-1[2]	1100
JL 24[2]	540
SE	±120
Trial mean	1329
CV(%)	16

1. Rust and late leaf spot-resistant parent.
2. Foliar diseases-susceptible cultivars.

Table 7. Performance of some promising entries in the groundnut foliar diseases-resistant F_6 lines trials (irrigated), ICRISAT Center, rainy season 1984.

Pedigree	Pod yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Disease reaction[1] Rust	Disease reaction[1] Late leaf spot
(Robut 33-1-21-11-B1-B1-B1-B1 x PI 407454)F_6 B	6820	4790	6	8
(Robut 33-1 x Comet)F_6 B x NC Ac 17133(RF)F_6 B	6470	3540	8	8
(Faizpur 1-5 x DHT 200)F_6 B	6330	4790	9	
(Ah 8254 x NC Ac 17090) F_7 B x L.No 95-A)F_6 B	6070	5210	4	7
Controls				
NC Ac 17090[2]	5140	5890	2	6
ICGS 11[3]	3290	6150	8	8
Robut 33-1[3]	2830	5760	9	9
JL 24[3]	4240	5040	9	9
SE	±401	±293	±0.4	±0.4
Trial mean	4417	5135	6.2	7.2
CV (%)	16	10	12.1	9.1

1. Field disease scored on a 1-9 scale, where 1 = no disease, and 9 = 50 - 100% foliage destroyed.
2. Rust and late leaf spot-resistant parent.
3. Foliar diseases-susceptible cultivars.

Table 8. Yields (kg ha^{-1}) of a foliar diseases-resistant, and two susceptible groundnut cultivars, with and without fungicide application from field trials, ICRISAT Center and farmer's field, rainy season 1984.

	Mean yields of dried produce (kg ha^{-1})			
	Pods		Haulms	
Genotypes	No spray	Daconil®[1] applied	No spray	Daconil®[1] applied
ICRISAT Center				
FDRS 18[2]	1290	1510	3870	4640
JL 24[3]	1110	1320	1380	1780
Local[4]	1110	1480	1170	2770
SE	±172		±151	
CV(%)	18		9	
Farmer's field				
FDRS 18[2]	670	670	1770	1810
JL 24[3]	900	910	1220	1310
Local[4]	670	710	1380	1350
SE	± 113		±174	
CV(%)	21		17	

1. Daconil® (chlorothalonil) applied at 10-day intervals.
2. Rust and late leaf spot-resistant breeding line.
3. Recommended cultivar (susceptible).
4. Farmer's own seed.

Table 9. Yield (kg ha^{-1}), shelling characteristics, and dried seed resistance to *Aspergillus flavus* in selected groundnut breeding lines, ICRISAT Center, postrainy season 1983.

ICGS(AF) number	Pedigree	Pod yield (kg ha^{-1})	SMK[1] yield (kg ha^{-1})	Shelling (%)	100-kernel mass (g)	Seed colonization (%)[2]
Trial 24						
6	(J 11 x PI 337394F)	5870	3640	70	51	15.2
9	(MH 2 x PI 337409)	5850	4310	77	41	16.4
11	(J 11 x PI 337394F)	5800	3820	72	44	6.5
22	(MH 2 x PI 337394F)	5740	3880	75	49	10.7
	Controls					
	J I 11[3]	5580	3720	73	50	12.9
	JL 24[4]	5260	3510	74	40	22.6
	Robut 33-1[4]	5000	3250	74	55	33.4
	UF 71513-1[3]	5250	3410	71	43	11.6
	SE	±382	±252	±2.2	±1.7	±2.3
	Trial mean	5250	3430	72	46	16.3
	CV (%)	9	9	4	5	17
Trial 25						
28	(Goldin 1 x Faizpur 1-5) x UF 71513-1)	6600	3570	63	66	17.0
32	(NC Fla 14 x UF 71513-1)	5650	3790	71	38	11.3
	Controls					
	J 11[3]	5190	3540	73	59	11.1
	JL 24[4]	4320	2720	71	48	23.9
	Robut 33-1[4]	4490	2850	70	56	33.0
	UF 71513-1[3]	4830	3250	72	41	13.4
	SE	±357	±258	±2.3	±2.8	±4.0
	Trial mean	5150	3100	68	49	24.3
	CV (%)	9	10	4	7	20

1. SMK = Sound mature kernels.
2. Percentage of rehydrated, mature, stored seeds colonized by *A. flavus* in resistance tests. Means of 2 samples $replication^{-1}$.
3. Resistant controls.
4. Susceptible controls.

We modified the usual mass-pedigree breeding system to include a stage of progeny-row testing and selection in the F_3, based on plant-to-row progenies obtained from selected F_2 plants. We grew 2986 such F_3 single-plant progenies in the 1984 rainy season and made 780 F_4 bulks, based on progeny rather than plant performance. These will be handled as progeny bulks from the F_4 stage onwards and mass selections will be made within each bulk. We also grew 479 bulk progenies from the F_4 to F_{10} generations, and selected 351 bulks for advance and yield testing next season. In the 1984 rainy season six F_2s with dry seed-resistant parental lines in their pedi-

Table 10. Pod yield (kgha^{-1}) of some selected groundnut breeding lines at five Indian locations, rainy season 1984.

ICGS(AF) number	Pedigree	Pod yield (kg ha^{-1}) ICRISAT Center HI[1]	LP	Dharwad	Bhavani-sagar	Hisar	Mean
Trial 37							
28	[(Goldin 1 x Faizpur 1-5) x UF 71513-1]	3860	790	3190	1720	5210	2953
2	(MGS 7 x PI 337409)	2770	860	3630	2740	3610	2724
3	(MGS 7 x PI 337409)	3060	1010	3790	2350	3390	2718
7	(Ah 32 x PI 337409)	2990	760	4030	2100	3510	2679
5	(J 11 x PI 337394F)	2960	490	3500	3040	3200	2636
10	(HG 1 x PI 337394F)	3140	860	3440	2250	3250	2588
22	(SM 1 x PI 337394F)	2590	760	3430	2130	3740	2531
12	(UF 71513-1 x PI 337394F)	2370	870	3600	2540	3270	2530
16	(MH 2 x PI 337394F)	2450	630	3560	2330	3610	2517
	Controls						
	J 11 (Source line)	2300	860	3770	2000	3150	2416
	JL 24 (National)	2520	420	3390	2040	3040	2281
	Robut 33-1 (Zonal)	2800	980	2750	1580	2970	2215
	UF 71513-I(Resistant line)	2260	860	3780	2310	3170	2476
	SE	±294	±133	±432	±345	±447	
	Trial mean	2560	710	3310	2050	3270	
	CV (%)	14	23	16	21	17	
Trial 38							
70	[(Robut 33-1 x 2821) x UF 71513-1]	3760	770	4960	2550	4040	3214
69	[(Robut 33-1 x 2821) x UF 71513-1]	3430	670	4650	2740	4440	3186
43	(F33 4A-B-14) x UF 71513-1)	4040	1070	4350	1710	3490	2931
37	(MH 2 x PI 337409)	3520	1070	4000	2350	3340	2855
78	(Faizpur 1-5 x UF 71513-1)	3670	540	4670	2140	3100	2826
82	(Robut 33-1 x Exotic)	3410	720	4680	2080	3180	2815
58	(Shulamit x Chico)	2660	940	4320	2420	3510	2771
61	[(Robut 33-1 x 2821) x PI 337409)]	3640	560	4330	1910	3170	2722
71	[(Robut 33-1 x 2821) x UF 71513-1]	4040	720	3330	2480	2970	2708
62	[(Robut 33-1 x 2821) x PI 337409]	2960	630	4430	2100	3030	2630
	Controls						
	J 11 (Resistant line)	3010	710	4470	1990	2760	2590
	JL 24 (National)	3130	670	4490	2150	1720	2432
	Robut 33-1 (Zonal)	3400	930	3860	1370	2430	2397
	UF 71513-1 (Resistant line)	2590	530	4490	1670	3260	2506
	SE	±1356	±162	±365	±327	±684	
	Trial mean	2970	710	3940	1800	2710	
	CV (%)	15	28	11	22	31	

1. HI = High input (60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays).
2, LI = Low input (20 kg P_2O_5 ha^{-1}, rainfed without insecticide sprays).

grees were grown under both high- and low-input conditions, and we made 292 single-plant selections to be advanced by the modified bulk system.

Resistance to aflatoxin production. We reported earlier varietal differences in rate and total accumulation of aflatoxin in seeds colonized by toxigenic strains of *A. flavus* (ICRISAT Annual Report 1980/81, pp. 171 and 173). Further tests on seed of 400 genotypes grown in the 1981 rainy season showed that genotypes supported aflatoxin production to levels ranging from 32 to 125 μg g^{-1} seed. Additional screening of 102 genotypes using seed from the 1982/83 season identified two low aflatoxin-producing genotypes, U4-7-5 and VRR 245, that had levels of less than 10 μg g^{-1} seed. These and other genotypes were grown in further trials and the poor ability of their seeds to support aflatoxin production was confirmed (Table 11).

In another test we compared seed from 30 genotypes with oil contents varying from 33 to 48%. We found no correlation between seed-oil content and ability to support aflatoxin production.

Table 11. Aflatoxin production μg g^{-1}) in seed of selected groundnut genotypes inoculated with a toxigenic strain of Aspergillus flavus, ICRISAT Center, 1983 and 1984.

	Aflatoxin B1 (*μg g^{-1}* seed)		
	Postrainy season trials[1]		Rainy season trials[1]
Genotypes	1982/83	1983/84	1983
Ah 813	97.9	62.4	24.8
Ah 1069	66.2	44.8	16.3
26-5-1	55.7	35.6	30.8
56-106	36.1	26.0	7.5
U4-7-5	5.9	5.8	5.2
VRR 245	6.1	5.8	4.4
J 11	148.4	100.1	89.0
TMV 2	185.9	137.9	117.8
SE		±1.9	
CV (%)		9.8	

1. All tested in 1984.

Table 12. Effect of seed maturity at harvest on groundnut seed infection by *Aspergillus flavus,* and aflatoxin contamination, ICRISAT Center, rainy season 1984.

	Seed infection by *A. flavus* and aflatoxin contamination			
	Pods sampled at			
Genotype	30 days before maturity	10 days before maturity	At optimum maturity	10 days after maturity
J 11	1.0[1]	2.01	3.3	5.3
	(1)[2]	(2)[2]	(6)	(11)
TMV 2	4.3	7.3	16.0	22.0
	(4)	(17)	(34)	(63)
EC 76446(292)	4.3	7.3	23.0	28.0
	(6)	(25)	(52)	(453)
M 13	6.3	8.3	18.7	26.3
	(2)	(12)	(24)	(150)
SE				+0.79
CV(%)			45	

1. Seeds infected by *A. flavus* (%).
2. Aflatoxin B1 content (μg kg^{-1}).

Field infection and aflatoxin contamination. Naturally-occurring seed infection by *A. flavus,* and aflatoxin contamination were recorded for several genotypes in the 1984 rainy season at ICRISAT Center. Seed infection and aflatoxin contamination were higher (Table 12) than recorded for the same genotypes grown at ICRISAT Center in 1983 (ICRISAT Annual Report 1983, p. 196). Severe drought conditions in 1984 may have favored the higher infection and toxicity.

Field trials for natural *A. flavus* infection. In the 1984 rainy season we grew 13 genotypes in replicated field trials at ICRISAT Center and on light, sandy soils at Tirupati and Bapatla in

Table 13. Natural seed infection (%) of 13 groundnut genotypes with A *spergillus flavus (AF)* and other fungi (OF) at three Indian locations, rainy season 1984.

	Seeds infected (%)					
	ICRISAT Center		Bapatla		Tirupati	
Genotypes	AF	OF	AF	OF	AF	OF
UF 71513	1.5(0.11)[1]	6.0 (0.25)	0.9 (0.09)	5.2 (0.23)	1.4(0.11)	2.5(0.16)
PI 337394F	1.5 (0.11)	10.0 (0.32)	1.6(0.13)	12.0 (0.35)	2.1 (0.14)	3.8 (0.19)
J 11	1.0(0.07)	4.0 (0.20)	0.6 (0.08)	4.7 (0.22)	1.0(0.09)	1.4(0.12)
Ah 7223	1.0(0.07)	4.0(0.19)	0.9 (0.09)	3.1 (0.18)	0.9 (0.09)	1.5(0.12)
U4-47-7	0.5 (0.04)	3.5 (0.18)	1.6(0.13)	3.2(0.18)	1.1 (0.11)	1.2(0.11)
Var. 27	4.0(0.19)	8.5 (0.29)	3.1 (0.17)	9.4(0.31)	2.5 (0.16)	3.2(0.18)
AFYT 24/8	2.0(0.12)	7.0 (0.27)	2.5(0.16)	6.4 (0.25)	3.0(0.17)	3.0(0.17)
AFYT 24/19	2.5 (0.14)	5.0 (0.22)	2.3 (0.15)	6.5 (0.26)	2.9(0.17)	3.6(0.19)
TMV 2	3.5 (0.18)	11.0 (0.33)	3.4(0.18)	6.7 (0.26)	4.6 (0.21)	5.9 (0.24)
NC Ac 17090	5.5 (0.23)	10.0 (0.32)	4.0 (0.20)	9.6(0.31)	20.8 (0.45)	5.4 (0.23)
F_1-5xNC Ac 17090	3.5(0.18)	6.0 (0.25)	4.3(0.21)	18.1 (0.44)	6.6 (0.25)	4.2(0.21)
Gangapuri	6.0 (0.25)	11.5(0.35)	4.8 (0.22)	15.7(0.41)	14.8 (0.38)	7.1 (0.27)
EC 76446(292)	10.5 (0.33)	19.0 (0.45)	6.6 (0.26)	43.1 (0.72)	10.5 (0.34)	18.2(0.44)
SE	±(0.031)	±(0.019)	±(0.013)	±(0.016)	±(0.036)	±(0.015)
CV(%)	(40.2)	(13.4)	(16.3)	(10.2)	(35.3)	(14.7)

1. Values in parentheses are arc sine transformations.

Andhra Pradesh State, India. We recorded natural infection of undamaged, mature seeds by *A. flavus* and other fungi, and found significant varietal differences (Table 13).

Addition of *A. flavus* inoculum to soil around pods. We reported earlier (ICRISAT Annual Report 1982, pp. 181-182 and 186) that the addition of *A. flavus* inoculum to soil around developing pods increased pod and seed invasion by the fungus. Further trials from 1982 to 1984 have confirmed the usefulness of this practice to enhance pre-harvest seed invasion by *A. flavus,* thus assisting in resistance screening.

Virus Diseases

Bud Necrosis Disease (BND)

During the 1983/84 rainy season we screened germplasm accessions, breeding lines, and

Groundnut leaf showing typical early symptoms of bud necrosis virus infection, ICRISAT Center, rainy season 1984.

interspecific hybrids for field resistance to BND. Several high-yielding lines with desirable pod and seed characteristics showed significantly lower disease incidence than the control cultivar, TMV 2. These lines will be evaluated in multilocational testing in India. Fourteen high-yielding, breeding and germplasm accessions with low BND incidence were selected. PYT 2-20 B_3 was outstanding in terms of both pod yield and low BND incidence.

Germplasm accessions with low BND incidence, in conditions where the thrips density was not lower than the controls, were detected in two advanced screening trials. More-advanced lines showing resistance to the BND vector were also detected.

Peanut Clump (PCV)

Causal agent. Five geographically-separated isolates of peanut clump virus (PCV) (ICRISAT Annual Report 1982, p.197) were shown to possess similar particle morphology and density, and similar molecular weight of the coat protein. Collaborating with the Scottish Crop Research Institute (SCRI), Invergowrie, UK, we studied in detail the chemical properties and serological relationships of PCV isolates. PCV was shown to contain two RNA species, both required for infectivity. Three PCV isolates failed to react with two West African PCV isolates, or with several *Polymyxa-transmitted* viruses. When the two RNA species were translated in a reticulocyte lysate system, the large RNA species was translated into three polypeptides and the coat protein gene was located in the smaller RNA species.

Transmission. The fungus *Polymyxa graminis* has been found in all PCV-infested soils (ICRISAT Annual Report 1982, p. 197). Airdried soils stored at room temperature for over 2 years, retained infectivity. All PCV-infected graminaceous plants contained *P. graminis* cystosori. We studied the effect of temperature on PCV infection of wheat and sorghum by exposing infested soils to various temperatures in incubators. None of the graminaceous hosts were infected at 15-20° C; exposure to 25° C and above was required for infection. This result confirms our field observations that the disease occurs in crops raised in the warm summer and rainy seasons, crops raised in the colder postrainy season escape the disease.

Resistance screening. In the 1984 rainy season we grew 20 wild *Arachis* species, 50 interspecific hybrids, 35 breeding lines, and 802 germplasm accessions, in a PCV-infested field at Bapatla. *Arachis* species 30036 did not become infected, and nine germplasm accessions showed low percentages of infected plants. These entries will be retested in 1985.

Peanut Mottle (PMV)

Resistance screening. Employing a field mechanical-inoculation method, we screened 246 germplasm accessions and breeding lines in the 1983/84 postrainy and 1984 rainy seasons for resistance to PMV. Three breeding lines which showed less than 5% yield loss (ICRISAT Annual Report 1983, p. 199) were tested in a replicated trial and one of them showed a mean yield loss of less than 10%, while over 50% of the plants showed no significant yield loss. Seed from these plants will be sown in advanced screening trials in 1985.

Further testing of over 13 000 seeds each of genotypes EC 76446(292), NC Ac 17133 (RF), and Ah 7171 confirmed that they did not seed-transmit PMV (ICRISAT Annual Report 1982, p. 189). Since NC Ac 17133 (RF) and EC 76446(292) are resistant to groundnut rust and late leaf spot, they were earlier crossed with several high-yielding cuitivars, and these crosses were tested for PMV seed transmission. Although PMV was seed-transmitted in most of these breeding lines, in one selection from a cross involving FSB 7-2 and EC 76446(292), PMV was not seed-transmitted through the 3000 seeds so far tested.

Groundnut Rosette (GRV)

Collaborating with SCRI and with the USAID Peanut Collaborative Research Support Pro-

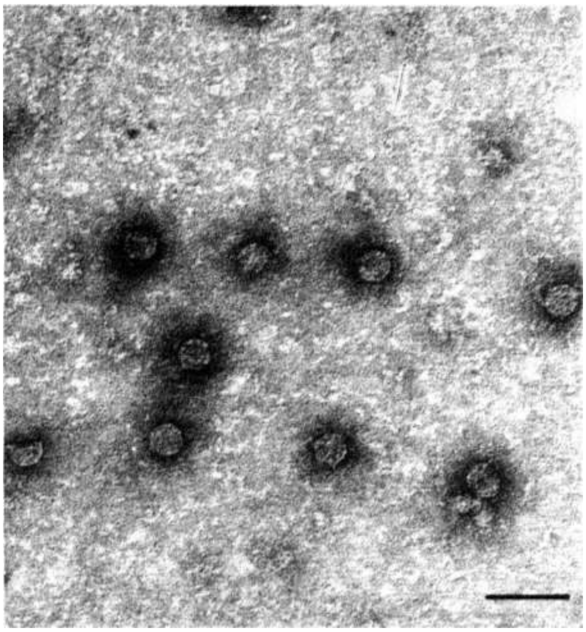


Figure 11. Particles of groundnut rosette assistor virus, trapped by antiserum to bean leaf-roll virus in immunosorbent electron microscopy, from crude extracts of an aphid-inoculated groundnut plant; the bar (1 cm) represents 56 nm. (Courtesy G. Duncan, Scottish Crop Research Institute.)

gram (CRSP), the causal viruses of groundnut rosette disease were investigated at SCRI. Evidence was obtained to show that rosette was caused by two viruses. One of them, GRV is mechanically-transmissible and produces typical symptoms in groundnut. For GRV to be transmitted by aphids, co-infection with a luteovirus (Fig. 11), serologically-related to bean leaf-roll virus is necessary. Local lesion hosts for detection, and systemic hosts for maintenance of GRV have been identified. GRV was partially purified, and identified as single-stranded RNA with a molecular weight of 1.5-1.6 million daltons.

Peanut Stripe (PStV)

Collaborating with the USAID Peanut CRSP, we characterized peanut stripe virus (PStV), that was introduced into the USA in groundnut seed material. PStV was identified as a potyvirus. An antiserum was produced and methods were developed to detect PStV in plant and seed material.

Insect Pests

Incidence at ICRISAT Center

The groundnut leaf miner *(Aproaerema modicello)* was the most noteworthy insect pest in 1984. Its density was not remarkable in the postrainy season but wet-season crops that rely on residual soil water were badly damaged by this pest, presumably because of the lack of rainfall in July and August. Protected plots yielded significantly more than unprotected plots.

Jassid *(Empoasca kerri)* numbers did not reach high levels during the year, but they were sufficient to cause obvious damage in susceptible lines. Their numbers markedly increased once rain fell in September. *Frankliniella schultzei* and *Scirtothrips dorsalis,* the two most commonly encountered thrips species, were usually present in both seasons, but never at crippling levels. However, there was an 80% incidence of bud necrosis disease (BND). BND is caused by tomato spotted wilt virus (TSWV) that is transmitted by *F. schultzei* in the rainy season.

White grubs (Lachnosterna fissa) and the tobacco caterpillar *(Spodoptera litura)* were not a problem in 1984. However, a pod-boring insect, probably a species of earwig, caused considerable damage to groundnut plants growing in a Vertisol field.

Preliminary Screening for Host-Plant Resistance

Aphids (*Aphis craccivora*). We screened 675 genotypes for resistance to *A. craccivora* and found four that inhibited aphid growth rates. This is the first time we have found any signs of resistance to this species.

Jassids (*Empoasca kerri*). The screening of a further 1470 germplasm accessions for jassid resistance during the 1984 rainy season means that we have assessed well over half the available material. Of the 1470 accessions, 15 were retained for further screening. In the same context we looked at 244 lines with resistance to foliar diseases, 202 *Arachis chacoense* derivatives, and 58 advanced breeding lines. There was success in all categories, in that we detected lines with significantly lower levels of damage symptoms than susceptible and resistant controls (Table 14).

Thrips (*Frankliniella schultzei* and *Scirtothrips dorsalis*). Damage levels were not high, so that the results of preliminary and secondary screening were not sufficiently clear to give definitive results. However, several germplasm accessions and the selections Robut 33-1 x NC Ac 2214-19 and TMV 4 x (Robut 33-1 x NC Ac 2214-14) were highly promising against both species.

Table 14. Groundnut genotypes with low incidence of jassid (*Empoasca kerri*) symptoms, ICRISAT Center, rainy season 1984.

Genotype	Yellowed foliage (%)
Ah 7729	2.0 (8.1)1
NC Ac 6	2.7 (9.4)
M 896-76 (1)	3.0 (9.9)
NC Ac 1787	3.3 (10.3)
NC Ac 1006	3.7 (10.4)
NC Ac 1807	4.3 (11.9)
M 57-72	5.0(12.8)
RC 44	5.0(12.8)
M 399-72	5.0 (12.8)
NC Ac 1694	5.7(13.7)
M 79-76(1)	5.7 (13.2)
NC Ac 1804	5.7(13.2)
NC Ac 2139	5.7(13.7)
EC 99219	5.7 (13.7)
M 137-74	6.3 (14.0)
PI 23442	6.3 (14.0)
M 6-76	6.7(14.8)
Susceptible control	
TMV 2	25.3 (30.2)
SF	± (2.11)
Trial mean (n = 87)	8.5 (16.54)
CV (%)	(22.1)

1. Values in parentheses are arc sine transformations.

Groundnut leaf miner (*Aproaerema modicella*). One of the breakthroughs of the 1984 postrainy season was the discovery of 33 lines, that had considerably less leaf miner damage than the other 1452 lines tested. Several of these (V 20, NCAc 12, S1, and 75-72 M 13) also had good agronomic characteristics.

Rust-red flour beetle (*Tribolium castaneum*). Ah 8418 was selected from 526 other lines for resistance to the rust-red flour beetle. The number of larvae produced, and percentage seed damaged were significantly lower when compared to the susceptible line, APAU 4.

Breeding for Pest Resistance

Generation advance and selection. Eleven hundred bulk selections from different generations (F_2 to F_9) were grown in the postrainy

Foliar damage in groundnut caused by leaf miner (*Aproarema modicella*). In the 1984 rainy season and the 1983/84 postrainy season this pest destroyed up to 40% of the groundnut leaf area in fields that were not treated with insecticide. There was a considerable yield reduction as a result of this damage. ICRISAT Center, rainy season 1984.

season for generation advance, screening against thrips, and for selection for various desirable agronomic traits including yield per se. Based on plant type, resistance, and other traits, we made 1500 bulk selections for further evaluation. Several new crosses were attempted, involving new sources of resistance to thrips and jassids, and cultivars with low BND incidence. Some of the high-yielding, pest-resistant breeding lines have also been crossed with foliar disease-resistant, interspecific derivatives to combine resistance to pest and diseases, and to broaden the genetic base for agronomic traits.

During the 1983/84 postrainy season under natural infestations, 200 advanced-generation breeding lines with varying levels of thrips and jassid resistance were evaluated for their yield potential and thrips resistance along with standard control cultivars. Pod yields and percentage *F. schultzei* leaf damage are shown in Table 15 for some resistant selections that significantly outyielded the control cultivars. Several breed-

Table 15. Pod yield (kg ha^{-1}) of groundnut selections resistant to thrips *(Frankliniella schultzei)* under natural infestation, ICRISAT Center, postrainy season 1983/84.

Identity	Pedigree	Leaflets damaged (%)	Pod yield (kg ha^{-1})	Shelling (%)
	Trial 1 (PRT 7 x 7L)			
ICGPRS 13	(Robut 33-1 x NC Ac 2214) F_9B_1	12	6670	73
ICGPRS 10	(Robut 33-1 x NC Ac 2214) F_9B_2	20	6000	69
ICGPRS 2	(Robut 33-1 x NC Ac 2214) F_9B_1	22	5960	72
ICGPRS 8	(Robut 33-1 x NC Ac 2214) F_9B_3	15	5810	70
ICGPRS 17	(M 13 x NC Ac 2214) F_9B_2	14	5670	74
ICGPRS 4	(Robut 33-1 x NC Ac 2214) F_9B_1	13	5620	66
Controls				
Robut 33-1		26	3220	73
J 11		24	4710	70
JL 24		34	3720	74
NC Ac 343		14	5840	61
SE		±3	±299	
Trial mean (n = 49)		24	4930	
CV (%)		20	11	
	Trial 2 (PRT 8 x 8L)			
ICGPRS 36	[(NC Ac 2232 x NC Ac 2214) x TG 17] F_6B_1	17	6310	71
ICGPRS 30	[(Robut 33-1 x NC Ac 2821) x NC Ac 2232] F_6B_3	21	6170	70
ICGPRS 77	[(Goldin 1 x Faizpur 1-5) x NC Ac 2232] F_1B_1	11	6040	71
ICGPRS 68	(28-206 (France) x NC Ac 2214) F_6B_1	13	5550	67
Controls				
Robut 33-1		27	4470	72
J 11		26	4240	73
JL 24		39	3340	72
NC Ac 343		14	5270	62
SE		±2.2	±259	
Trial mean (n = 64)		27	4510	
CV (%)		14.3	10	

Continued

Table 15. *Continued*

Identity	Pedigree	Leaflets damaged (%)	Pod yield (kg tor')	Shelling (%)
	Trial 3 (PRT 9 x 9 L)			
ICGPRS 35	(TG 1 x NC Ac 343) F_7B_1	15	6700	71
ICGPRS 63	(F33 4A-B-14 x NC Ac 2214) F_7B_2	13	6470	70
ICGPRS 37	(Mani Pintar x NC Ac 2232) F_7B_1	13	6360	73
ICGPRS 21	(Manfredi 68 x NC Ac 2232) F_7B_3	21	6300	74
ICGPRS 19	(G 201 x NC Ac 2232) F_7B_1	18	6270	71
ICGPRS 24	(Makulu Red x NC Ac 343) F_7B_2	23	6260	74
ICGPRS 22	(28-206 x NC Ac 10247) F_7B_2	15	6010	71
ICGPRS 28	[X52-X-X-3-B x (Robut 33-1 x NC Ac 2214)] F_7B_1	15	6010	71
ICGPRS 36	(Mani Pintar x NC Ac 2232) F_7B_1	9	5840	73
ICGPRS 34	(TG 1 x NC Ac 343) F_7B_1	15	5820	70
ICGPRS 57	[(X52-X-X-3-B x M 13) x NC Ac 2214] F_7B_2	11	5690	70
Controls				
Robut 33-1		15	5200	73
J 11		20	3750	72
JL 24		29	3390	71
NC Ac 343		11	4940	69
SE		±1.6	±321	
Trial mean (n = 81)		22	4750	
CV (%)		12	12	

ing lines, though low-yielding, showed very high levels of resistance to thrips and jassids. These selections are being further crossed with high-yielding resistant or moderately-resistant lines to improve their agronomic character.

Generation advance, selection, and yield trials. Three hundred selections in various generations were sown for generation advance and selection for pest resistance and various desirable agronomic traits in the rainy season. Several useful selections made in early generations possess resistances to both thrips and jassids, they also have excellent pod and kernel traits. In F_2 populations derived from crosses of pest-resistant breeding lines with interspecific derivatives we detected a number of selections with large pods and multiple resistance to several pests, and to rust, and late leaf spot diseases.

Six hundred and seventy-eight advanced-generation selections with varying levels of thrips and jassids resistance were yield-tested under natural pest infestations under high- and low-input conditions in pesticide-free areas. (High-input conditions = irrigated, 60 kg P_2O_5 ha^{-1}, and herbicides applied. Low-input conditions = nonirrigated, 20 kg P_2O_5 ha^{-1} applied, without herbicides. No insecticides were used in this experiment.)

Yields of the fifteen highest-yielding, Virginia bunch-type selections are given in Table 16. ICGPRS 35, 39, 59, 92, 94, and 97 were the high-yielding selections under both high- and low-input conditions. ICGPRS 90, 8, 94, 97, 104, 33, 39, 40, 106, 107, 59, and 108 had excellent pod and kernel characteristics.

Among the sixteen F_8 high-yielding, spanish-bunch selections, 13 out-yielded the susceptible controls, ICGS 26 and JL 24. The resistant control, NC Ac 343, yielded well, but it is a long-duration Virginia cultivar, whereas the breeding lines mature in 120 days. Among these, (Man-

Table 16. Pod yield (kg ha^{-1}) of some high-yielding thrips- and jassid-resistant Virginia bunch groundnut selections under natural pest infestation and high- and low-input conditions, ICRISAT Center, rainy season 1984.

Identity	Pedigree	Pod yield (kg ha^{-1})
High-input conditions[1]		
ICGPRS 91	(Robut 33-1 x NC Ac 2214)	3550
1CGPRS 35	(TG 1 x NC Ac 343)	3480
ICGPRS 43	(TMV 10 x NC Ac 2232)	3430
ICGPRS 40	[Mani Pintar x (Robut 33-1 x NC Ac 2214)]	3420
ICGPRS 108	(28-206 (France) x NC Ac 10247)	3310
ICGPRS 39	[(Mani Pintar x Robut 33-1) x NC Ac 2214]	3310
ICGPRS 106	(Makulu Red x NC Ac 2232)	3250
ICGPRS 94	(Robut 33-1 x NC Ac 2214)	3060
ICGPRS 96	(Robut 33-1 x NC Ac 2214)	3060
ICGPRS 104	(NC 17 x NC Ac 343)	3020
ICGPRS 59	[X52-X-X-3-B x (M 13 x NC Ac 2214)]	3020
ICGPRS 107	(Manfredi 68 x NC Ac 343)	2960
ICGPRS 92	(M 13 x NC Ac 2214)	2940
ICGPRS 97	(Robut 33-1 x NC Ac 2214)	2940
ICGPRS 87	(Robut 33-1 x NC Ac 2214)	2920
Controls		
ICGS 6		2500
Robut 33-1		2580
NC Ac 343		2290
SE		±304
Trial mean (n = 64)		2510
CV (%)		17
Low-input pesticide-free conditions[2]		
ICGPRS 39	[Mani Pintar x (Robut 33-1 x NC Ac 2214)]	1540
ICGPRS 59	[X52-X-X-3-B x (M 13 x NC Ac 2214)]	1450
ICGPRS 92	(M 13 x NC Ac 2214)	1450
ICGPRS 37	(Mani Pintar x NC Ac 2232)	1430
ICGPRS 94	(Robut 33-1 x NC Ac 2214)	1410
ICGPRS 90	(Robut 33-1 x NC Ac 2214)	1400
ICGPRS 8	(Robut 33-1 x NC Ac 2214)	1390
ICGPRS 62	(Manfredi 68 x NC Ac 343)	1370
ICGPRS 51	[(Mani Pintar x Robut 33-1) x NC Ac 2232]	1340
ICGPRS 35	(TG 1 x NC Ac 343)	1330
ICGPRS 36	(Mani Pintar x NC Ac 2232)	1320
ICGPRS 103	(Manfredi 68 x NC Ac 343)	1320
ICGPRS 97	(Robut 33-1 x NC Ac 2214)	1310
ICGPRS 109	(NC 17 x NC Ac 343)	1300
ICGPRS 33	(NC 17 x NC Ac 34)	1290
Controls		
ICGS 6		1010
Robut 33-1		1200
NC Ac 343		1030
SE		±98
Trial mean (n = 64)		1130
CV (%)		15

1. See Table 10 footnote 1. 2. See Table 10 footnote 2.

fredi x NC Ac 343)F_8B_2, (Tifspan x NC Ac 2214)F_8B_3, (Goldin I x NC Ac 2232)F_8B_3, [(NC Ac 2232 x NC Ac 2214) x NC Ac 343)]F_8B_3, (NC Ac 17352 x NC Ac 2232)F_8B_2, (MGS 9 x NC Ac 2232)F_8B_2, [(NC Ac 2232 x NC Ac 2214) x NC Ac 343)]F_8B_3, (Manfredi 68 x NC Ac 343)F_8B_3, (Robut 33-1 x NC Ac 2232)F_8B_3, and (Robut 33-1 x NC Ac 2232)F_8B_3, have excellent pod and kernel characteristics. Several of the lines performed well under both high- and low-input conditions.

Mechanisms of Host Resistance

We studied various aspects of jassid biology on 13 resistant and one susceptible cultivar in a screenhouse trial. The parameters studied were jassid longevity, fecundity, body mass, and reproductive potential; the plant parameters were leaf lamina and midrib hairiness, and total phenolic (tannin) content. The results (Table 17) showed that resistance to jassids can be related to the presence of long and dense trichomes, a thick cuticle, and the presence of tannins. The cause of jassid resistance in three of the lines tested was not discovered.

Table 17. Nature and mechanism of groundnut resistance to jassids.

Nature of resistance	Accession No. (NC Ac)
Oviposition reduced	2214[1], 2230[1], 2232[2], 2240B[1], 2243[2,3]
Feeding reduced	2214[1], 2232[2], 2240[1]
Fecundity reduced	2242[2], 2232[1], 2240[1]
Antibiosis	343[3], 1705[2], 2242[2]
Not known	785, 2144, 2666

Mechanism of resistance:
1. High density, long hairs.
2. Thick cuticle.
3. High tannin content.

Stresses from Lack of Nutrients

Nitrogen Fixation and Nodulation

Response of Cultivars to *Rhizobium* Strain NC 92 and Fertilizer Nitrogen

In previous trials we showed that yields of cultivars Robut 33-1, JL 24, and ICGS 27 increased in response to inoculation with *Rhizobium* strain NC 92. We also observed that Robut 33-1 responded to the application of fertilizer nitrogen (ICRISAT Annual Report 1983, pp.205-207). We conducted a trial in the 1983/84 postrainy season with an expanded range of genotypes to identify other cultivars that may respond to NC 92, and to see if all those that respond also respond to nitrogen fertilizers. We found that ICGS 4, ICGS 5, ICGS 6, ICGS 11, and ICGS 12 all responded positively to NC 92 inoculation, but only ICGS 4, ICGS 11 and ICGS 12 also responded to applications of fertilizer nitrogen (Table 18).

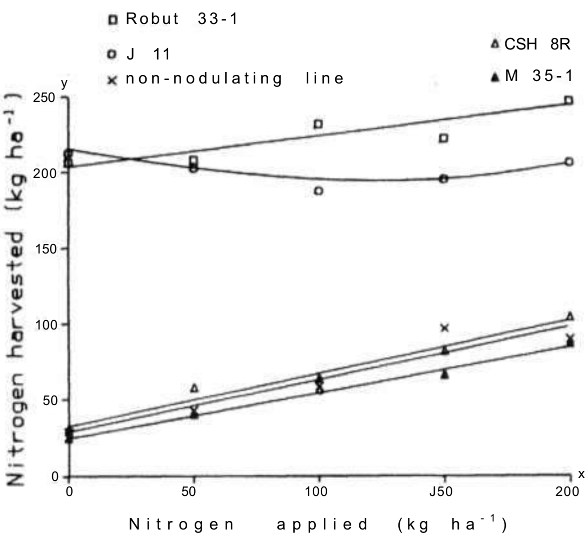
Estimates of the amount of nitrogen fixed by a given legume crop can be made by comparing the nitrogen accumulated in that crop with the amount of nitrogen provided to a non-fixing crop (usually of another species) to estimate the amount that would have been taken up from the soil. The major uncertainty of this differential-uptake method has been that the uptake by another species may be a poor reflection of the amount of nitrogen taken up by the legume from that soil.

During the 1983/84 postrainy season we compared nitrogen accumulation by two nodulating genotypes with a non-nodulating groundnut and two sorghum cultivars. All comparisons were made at five levels of applied N, ranging from 0 to 200 kg nitrogen ha^{-1}. Accumulation by the nodulating groundnuts was affected by the application of nitrogen but the cultivars differed, Robut 33-1 responded positively, and J 11 negatively. However, the non-nodulating groundnuts and sorghum responded in a similar and linear fashion to the applied nitrogen (Fig. 12). This result suggests that sorghum gives a reliable estimation of the amount of nitrogen available from the soil for groundnuts.

Table 18. Effect of *Rhizobium* strain (NC 92) inoculation and nitrogen fertilizer on pod yield (kg ha^{-1}) of five groundnut genotypes, ICRISAT Center, postrainy season 1983/84.

Cultivars	Treatment: Control (noninoculated nonfertilized)	Inoculated (*Rhizobium* strain NC 92)	Nitrogen applied (200 kg ha^{1})	Mean	SE
ICGS 12	5300	5810	5690	5600	
ICGS 11	5140	5730	5690	5520	
ICGS 4	3580	4320	3970	3960	±192
ICGS 5	4570	5330	4080	4660	
ICGS 6	5340	5530	4940	5270	
SE		±333			
Mean	4785	5342	4875		
SE mean		±149			

Field trial to compare nitrogen accumulation by nodulating and non-nodulating genotypes of groundnut and two sorghum cultivars. The groundnuts in the foreground are nodulating types obviously growing better than the non-nodulating one (center), ICRISAT Center, postrainy season 1983/84.



□ **$y = 204 + 0.19x$, rse = 8.99**
r = 0.88, *P* < 0.05

○ **$y = 213 - 0.39x + 0.002x^2$, rse = 4.27**
r = 0.95, *P* < 0.1

× **$y = 28 + 0.35x$, rse = 10.968**
r = 0.94, *P* < 0.05

△ **$y = 33 + 0.34x$, rse = 5.47**
r = 0.98, *P* < 0.01

▲ **$y = 25 + 0.30x$, rse = 2.65**
r = 0.99, *P*< 0.01.

Figure 12. Effect of nitrogen fertilizer applied (kg ha^{-1}) on nitrogen uptake measured as nitrogen harvested (kg ha^{-1}) in: a. two nodulating groundnut genotypes, Robut 33-1 and J 11; b. a non-nodulating groundnut line, and c. two sorghum genotypes, CSH 8R and M 35-1, ICRISAT Center, postrainy season 1983/84.

In this experiment the amount of nitrogen fixed by the nodulating groundnut was estimated to be 180 kg ha^{-1}.

Screening Methods to Identify *Rhizobium* Inoculant Strains

Two major criteria are generally used to identify strains of *Rhizobium* for legume inoculants to be used by farmers. The first is the ability to fix greater amounts of nitrogen than native strains (efficiency), and the second is the ability to form nodules with the host plant in the face of competition for infection sites by native *rhizobia* (competitive ability). We studied the nitrogen-fixing efficiency and competitive ability of three *Rhizobium* strains, TAL 176, NC 43.3, and NC 92 in two-strain combinations, in pot culture in a greenhouse, and as single strains against the native population in a field at ICRISAT Center.

Using the conventional methods of measuring nitrogen-fixing efficiency we found that strain NC 43.3 fixed most nitrogen (Table 19). In two-strain combinations, and in the field TAL 176 was a poor competitor. In pot-culture conditions NC 43.3 was superior to NC 92, but in the field against the native *rhizobia,* NC 43.3 and NC 92 had similar competitive abilities (Table 20).

Based on these data, and conventional selection criteria for strain identification, NC 43.3 would be identified as the superior strain, however, these benefits do not relate to the relative performance of the strains in increasing pod yields since NC 43.3, despite similar competitive

Table 19. Effect of *Rhizobium* strains NC 92, TAL 176, and NC 43.3 (10^8 cells seed"^{1}) on groundnut cultivar Robut 33-1, greenhouse trial, ICRISAT Center, 1984.

Rhizobium strain	Total dry matter (g) plant$^{1-1}$	Nodule number plant^{-1}	Nodule mass (mg) plant^{-1}	N-content (%) plant^{-1}	Total N fixed (mg) plant^{-1}
TAL 176	4.1	173	91	3.7	152
NC 43.3	4.3	216	119	4.8	205
NC 92	4.1	169	102	4.0	161
SE	±0.20	±8.8	±6.2	±0.19	±19.9

Table 20. Percentage nodules formed on groundnut cultivar Robut 33-1 by three *Rhizobium* inoculant strains (NC 92, TAL 176, and NC 43.3) in two-strain combinations (10^6 cells of each strain $seed^{-1}$) in greenhouse pot culture, and as single strains (10^6 cells $seed^{-1}$) in field containing 10^2-10^4 native rhizobia g^{-1} dry soil, ICRISAT Center, rainy season 1984.

	Nodules formed by strain (%)		
	NC 92	TAL 176	NC 43.3
In pot culture			
NC 92: TAL 176	93	2	-
NC 92: NC 43.3[1]	48	-	77
77 TAL 176: NC 43.3	-	3	97
In field as single strain	20	1	17

1. Total values greater than 100% are due to double occupancy by NC 92 and NC 43.3,

ability and greater nitrogen-fixing efficiency does not increase yields while NC 92 does (ICRISAT Annual Report 1979/80, pp. 157 and 1982, p. 200).

This effect is being further investigated since it leaves some doubt about the value of the existing strain-identification procedures.

Effect of Sowing Depth on Yield

We reported earlier that deep sowing, as practiced by many farmers in south India, decreased nodulation and nitrogen fixation (ICRISAT Annual Report 1981, p. 186). During the 1984 rainy season we observed decreases in pod and haulm yields when groundnuts were sown 8-10 cm compared to 4-6 cm deep. The probable reasons for deep sowing are: to utilize residual soil moisture for germination and seedling growth; to protect the seed from birds and animals; and because conventional sowing devices place the seeds deeper than necessary.

Our results (Table 21) indicate that yield losses due to this practice could be substantial, and we also found that there was a significant interaction between the effects of sowing depth and cultivars, with Robut 33-1 being more affected than J 11, Shallow sowing is desirable if stand establishment can be assured. Research to overcome these problems by other methods could have a substantial impact on yields achieved by farmers. It is also possible that genotypes that suffer less yield loss when sown too deeply could be identified.

Iron Deficiency

Screening Breeding Lines for Iron Efficiency

In yield trials at Bhavanisagar during the 1984 rainy season several breeding lines showed severe iron chlorosis symptoms when the crop was 80 days old. We used this opportunity to screen for iron 'efficiency' among the breeding lines. Iron deficiency was scored on a 0-5 scale,

Table 21. Effect of sowing depth on pod and haulm yields (kg ha^{-1}) of two groundnut cultivars, ICRISAT Center, rainy season 1984.

	Pod yield (kg ha^{-1})				Haulm yield (kg ha^{-1})			
	Sowing depth (cm)				Sowing depth (cm)			
	4-6		8-10	SE[1]	4-6		8-10	SE[1]
Robut 33-1	5200		3400	±182	4230		3470	±164
J 11	2930		2220		3550		3260	
SE		±251				±184		
Mean	4060		2810		3890		3360	
SE mean		±129				±116		

1. SEs for comparing sowing depth within a cultivar.

Groundnut leaflets showing chlorosis due to severe iron deficiency, Bhavanisagar, rainy season 1984.

Table 22. Selected iron-efficient groundnut breeding lines[1].

Pedigree	Iron efficiency score[2]
NC 3033 (Small pod)	0.0
NC 3033 (Bold pod)	0.0
RMP 12	0.3
RMP 91	0.5
NC Ac 17142	0.5
ICGS(E) 42	0.5
ICGS(E) 30	o.s
PI 393527B	0.8
Controls	
J 11	2.3
JL 24	2.8
Robut 33-1	2.8
Chico	4.0

1. From three different trials.
2. On a 0-5 scale, where 0 = no deficiency and 5 = completely chlorotic. Average of three replicates.

where 0 = no deficiency and 5 = completely chlorotic, in 180 breeding and germplasm lines, each replicated three times in three different trials. Consistent scores were observed between replications. Eight lines were selected as iron-efficient (Table 22) based on consistently low scores across replicates. Both the small- and large-podded selections of NC 3033 showed no deficiency in all the replicates tested.

Plant Improvement

Breeding for High Yield and Quality

Postrainy Season 1983/84

Generation advance and selection. Five hundred bulk selections from different generations (F_2 - F_{13}) were generation advanced. Following selection for yield and other agronomic traits, 430 bulk selections from 270 crosses were retained for further selection and generation advance. We also identified Spanish bunch selections with large pods and seeds with tan or rose testa color. We evaluated progenies from interspecific crosses susceptible to foliar diseases for various agronomic traits, and 50 selections were retained for further evaluation.

We attempted new crosses of high-yielding ICGS lines with other germplasm lines having desirable agronomic traits. Crosses involving interspecific derivatives were also made to broaden the genetic base for various agronomic traits.

Yield trials at ICRISAT Center. Five hundred advanced-generation selections were tested for their yield potential compared to Robut 33-1 and ICGS 11 under high-input conditions in a broadbed-and-furrow (BBF) system. Pod yields of Spanish and Virginia bunch selections are presented in Table 23. All the selections in Table 23 have significantly outyielded both the minikit control cultivars by yielding more than 7000 kg dry pods ha^{-1}. The highest yield of 8000 kg pods ha^{-1} was recorded by the selection [(NC Ac

Table 23. Yield of Spanish and Virginia bunch selections outyielding both Robut 33-1[1] and ICGS 11[2], ICRISAT Center, postrainy season 1983/84.

Trial number	Pedigree	Dry pod yield (kg ha^{-1})	Growth habit	Yield of controls (kg ha^{-1})	
Trial 1 (F_6)	[(G 37 x PI 259747)F_6B_1 x Robut 33-1-21-11]F_6B_1	7640	SB	Robut 33-1[1]	6090
	[(M 13 x Robut 33-1)F_6B_1 x (53-68 x Robut 33-1)]F_7B_1	7440	VB,SB	ICGS 11[2]	6220
	(Robut 33-1 x 865)F_6B_1	7400	VB,SB	SE	±246
	(Robut 33-1 x 905)F_6B_1	7300	VB,SB	Trial mean (n = 36)	6450
	(Robut 33-1-21-11 x 877)F_6B_1	7220	VB	CV (%)	7
	[(53-68 x Robut 33-1)F_7B_1 x (MK 374 x Robut 33-1)F_7B_1]F_6B_1	7210	VR		
	(Robut 33-1 x 811)F_6B_1	7090	VB,SB		
	[(Robut 33-1 x NC Ac 2821)F_6B_1 x (USA 20 x TMV 10)F_6B_1]F_6B_1	7010	SB		
Trial 2 (F_5)	(ICGS 22 x ICGS 16)F_6B_1	7800	SB	Robut 33-1	6170
	[(ICGS 5 x (TMV 10 x Chico)F_6B_1]F_5B_2	7230	VB, SB	ICGS 11	5830
	[(ICGS 15 (TMV 10 x Chico)F_6B_1]F_5B_1	7130	SB, VB	SE	±332
	[(ICGS 24 x (TMV 10 x Chico)F_6B_1]F_5B_2	7130	VB, SB	Trial mean (n =49)	6230
	(NC Ac 17352 x Ah 114)F_5B_1	7120	VB	CV (%)	9
Trial 3 (F_8,F_9)	[(NC Ac 17090 x Robut 33-1)F_7B_1 x (M 13 x Robut 33-1)F_8B_1]F_9B_1	8010	SB	Robut 33-1	5380
	(Robut 33-1 x L.No.95-A)F_8B_1	7190	SB, VB	ICGS 11	6020
				SE	±396
				Trial mean (n = 25)	6150
				CV (%)	11
Trial 4 (NYT VB)	(Robut 33-1 x NC Ac 2731)F_8B_1	7250		Robut 33-1	5630
	(Florigiant x Robut 33-1)$F_{12}B_1$	7100		ICGS 11	6280
				SE	±227
				Trial mean (n = 18)	6230
				CV (%)	6
Trial 5 (F_{12})	(NC Ac 529 x Robut 33-I)$F_{12}B_1$	7240		Robut 33-1	5280
	(NC Ac 475 x Robut 33-1)$F_{12}B_1$	7010		ICGS 11	6040
				SE	±162
				Trial mean (n = 36)	5480
				CV (%)	5

1. Robut 33-1 = Virginia bunch control.
2. ICGS 11 = Spanish bunch control (SB).

17090 x Robut 33-1) F_7B_1 x (M 13 x Robut 33-l)F_8B_1)]F_7B_1. Many other selections significantly outyielded Robut 33-1, but not ICGS 11.

The oil content of these lines varied from 38 to 49% and the protein content from 16 to 28%.

Rainy Season 1984

Generation advance and selection. We grew 474 selections from 314 crosses in various generations (F_2-F_{14}) under high-input conditions. Useful selections were made, including large-seeded confectionery types.

High-yielding breeding lines and germplasm accessions with desirable agronomic traits were intercrossed to generate new populations with more genetic variability for various traits.

Yield trials. We yield-tested 220 advanced generations under high- and low-input conditions at ICRISAT Center and Bhavanisagar. Other trials at Anantapur, Dharwad, and Hisar were abandoned due to drought or soil salinity problems. Selected results from one of the trials are shown in Table 24. Several lines,such as (MGS 9 x Robut 33-1)F_{15},B1 and (Robut 33-1 x NC Ac 316)$F_{15}B_1$ yielded well under both high-and low-input conditions at ICRISAT Center.

Preliminary evaluation of new selections. Two hundred and seventy new selections, identified earlier, were evaluated for their performance against standard control cultivars under highl- and low-input conditions at ICRISAT Center in the rainy season. Of these, 150 selections were

Table 24. Kernel yields (kg ha^{-1}) of some high-yielding selections in three environments, ICRISAT Center (high- and low-inputs[1]) and Bhavanisagar, rainy season 1984.

	Yields (kg ha^{-1})			
	ICRISAT Center			
Pedigree	High input (Irrigated)	Low input (Rainfed)	Bhavanisagar (Irrigated)	Mean
(MGS 9 x Robut 33-1)$F_{15}B_1$	6290 (1)2	1470 (5)	1790(45)	3180
(MK 374 x Robut 33-1)$F_{15}B_1$	5750 (7)	1360(20)	2150(19)	3090
(MK 374 x Robut 33-1)$F_{15}B_1$	5740 (8)	1480 (4)	1930 (34)	3050
(Robut 33-1 x NC Ac 316)$F_{15}B_1$	6200 (2)	1450 (7)	1450 (59)	3030
[(Robut 33-1 x NC Ac 2821) x				
(Goldin 1 x Faizpur 1-5)]$F_{15}B_1$	5200(21)	1320 (28)	2480 (7)	3000
(M 13 x KU No.203)$F_{10}B_1$	5880 (5)	1340(22)	1710(50)	2980
Robut 33-1-12-10	5990 (3)	1310(29)	1580(54)	2960
(Florigiant * Ah 330)$F_{10}B_1$	5480 (14)	1490 (3)	1820(42)	2930
(Faizpur 1-5 x Ah 330)$F_{10}B_1$	5560 (12)	1170(43)	2000 (26)	2910
(FSB 7-2 x 75-23)$F_{10}B_1$	5150(28)	1380(13)	2100(21)	2880
Controls				
Robut 33-1[3]	4400	1160	1760	
ICGS 6[3]	5160	950	1860	
SE	±282	±129	±252	
Trial mean (n = 64)	5050	1250	1970	
CV (%)	10	18	22	

1. See Table 10 footnotes 1 and 2.
2. Figures in parentheses are yield ranks.
3. Virginia bunch types.

Table 25. Pod yields (kg ha^{-1}) of some high-yielding selections with excellent pod and kernel characteristics under high- and low-input conditions[1], ICRISAT Center, rainy season 1984.

High-input conditions		Low-input conditions	
Pedigree	Pod yield (kg ha^{-1})	Pedigree	Pod yield (kg ha^{-1})
[(Florigiant x NC Ac 17090) x (Dh 3-20 x P1 259747)]F_1B_1	6860	(ICGS 44 x F334A-B-14)F_5B_1	1580
(ICGS 21 x ICGS 38)F_6B_1	6690	(ICGS 49 x ICGS 4)F_5B_1	1550
(ICGS 21 x ICGS 38)F_6B_2		[(Florigiant x NC Ac 17090)x (Dh 3-20 x P1 259747)]F_5B_1	1440
(Ah 65 x F334A-B-14)F_6B_1	6600	(ICGS 46 x ICGS 36)F_5B_1	1420
(GAUG 1 x F334A-B-14)F_6B_1	6430	(Ah 65 x F334A-B-14)F_6B_1	1330
(ICGS 16 x F334A-B-14)F_5B_2	6420	(Var 2-5 x F334A-B-14)F_5B_1	1310
(ICGS 44 x F334A-B-14)F_5B_1	6420	(ICGS 21 x ICGS 38)F_6B_1	1290
(ICGS 44 x F334A-B-14)F_5B_1	6340	(GAUG 1 x F334A-B-14)F_6B_1	1270
(Sm 5 x F334A-B-14)F_6B_1	6250	(ICGS 21 x ICGS 38)F_6B_2	1250
(Var 2-5 x F334A-B-14)F_6B_1	6240	(F334A-B-14 x ICGS 6)F_6B_1	1240
(ICGS 24 x ICGS 27)F_6B_1	6070	(ICGS 24 x ICGS 27)F_6B_1	1220
(Var 2-5 x F334A-B-14)F_6B_1	6060	(ICGS 16 x F334A-B-14)F_5B_2	1190
(ICGS 16 x F334A-B-14)F_5B_1	5930	(ICGS 24 x ICGS 27)F_6B_1	1180
(ICGS 44 x F334A-B-14)F_5B_1	5920	(ICGS 44 x F334A-B-14)F_5B_1	1170
(ICGS 49 x ICGS 4)F_5B_1	5910	(Sm 5 x F334A-B-14)F_6B_1	1150
(ICGS 46 x ICGS 36)F_5B_1	5880	(ICGS 27 x F334A-B-14)F_5B_1	1100
(ICGS 27 x F334A-B-14)F_5B_1	5850	(F334A-B-14 x ICFGS 20)F_6B_1	1150
(ICGS 24 x ICGS 27)F_6B_1	5770	(ICGS 16 x F334A-B-14)F_5B_1	1080
(F334A-B-14 x ICGS 20)F_6B_1	5620	(ICGS 44 x F334A-B-14)F_5B_1	1070
Controls		Controls	
JL 24[2]	4560	JL 24[2]	700
Robut 33-1[3]	5660	Robut 33-1[3]	1300
SE	±306	SE	±108
Trial mean (n = 25)	5970	Trial mean (n = 25)	1200
CV (%)	9	CV (%)	15

1. See Table 10 footnotes 1 and 2.
2. Spanish bunch type.
3. Virginia bunch type.

rejected for having low yields and undesirable pod and kernel traits. Only 110 selections have been retained for further evaluation for various quality traits. Results for some of the high-yielding selections with excellent pod and kernel characteristics are shown in Table 25. Under high-input conditions the best eight selections significantly outyielded both JL 24 and Robut 33-1, whereas others were only significantly superior to JL 24. Selection [(Florigiant x NC Ac 17090) x (Dh 3-20 x P1 259747)]F_5B_1 produced the highest pod yield, 6860 kg dry pods ha^{-1}, a 50% yield increase over JL 24 and 20% over Robut 33-1. It ranked 3rd under low-input conditions when it yielded 1440 kg dry pods ha^{-1}. Similarly, most of these selections were significantly higher-yielding than JL 24 under the low-input conditions. Selection (ICGS 44 x F33

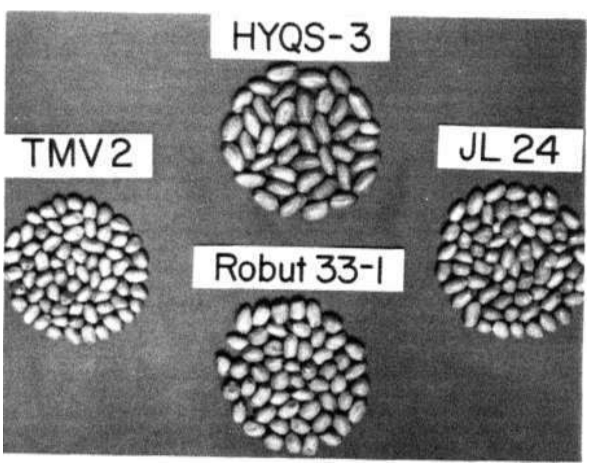
4A-B-14)F_5B_1 that gave the highest pod yield under low-input conditions ranked 8th under high inputs.

It is interesting to observe that one of the common parents in the pedigree of many of these selections is F334A-B-14, a Florida breeding line resistant to collar rot caused by *Diplodia* sp. This material might be of interest in areas where collar rot is a serious problem. It appears that F334A-B-14 has good combining abilities.

Breeding for the Confectionery Market

Large-seeded, well-shaped kernels receive a premium price on the world market for edible groundnuts. Exporting countries include Egypt, Malawi, the Peoples' Republic of China, Senegal, and Sudan. Many other countries are interested in developing either an export, or an internal trade in this type of groundnut.

In the 1983/84 postrainy season, large-seeded selections averaging 30-40 seeds $ounce^{-1}$ compared to 50-60 seeds $ounce^{-1}$ for the control cultivars Robut 33-1 and ICGS 11, were yield-tested at ICRISAT Center under high-input conditions. Many selections yielded over 6000 kg pods ha^{-1}, and four over 7000 kg ha^{-1} (Table 26). The number of seeds $ounce^{-1}$ is a quality estimate used by the confectionery trade.



Groundnut cultivar HYQS 3 (top) has well-shaped kernels, larger than the three commonly grown cultivars shown for comparision, ICRISAT Center, postrainy season 1983/84.

Table 26. Performance of selected confectionery groundnut selections [HYQ(CG)S], ICRISAT Center, postrainy season 1983/84.

Trial no.	Identity	Growth habit	Pod yield (kg ha^{-1})
1.	HYQ(CG)S8	SB/VB[3]	7005
	Controls		
	Robut 33-1[1]	VB	6093
	ICGS 11[2]	SB	6221
	SE		±246
	Trial mean (n=36)		6454
	CV (%)		7
2.	HYQ(CG)S13	SB	7875
	HYQ(CG)S14	VB	6965
	Controls		
	Robut 33-1	VB	6219
	ICGS 11[2]	SB	7264
	SE		±286
	Trial mean(n=21)		6753
	CV (%)		7
3.	HYQ(CG)S17	SB	7583
	Controls		
	Robut 33-1	VB	6000
	JL 24[2]	SB	5653
	SE		±345
	Trial mean (n=64)		5947
	CV (%)		10

1. Virginia bunch type.
2. Spanish bunch types.
3. SB=Spanish bunch, VB=Virginia bunch.

In the 1984 rainy season further trials were conducted under high- and low-input conditions at ICRISAT Center and Bhavanisagar. Yields of selected large-seeded entries having comparable yields to the small-seeded controls are shown in Table 27.

Breeding for Earliness

It is essential to know just when a cultivar is mature so that only early types are selected.

Table 27. Pod yields (kg ha^{-1}) of large-seeded confectionery groundnut selections [HYQ(CG)S] in three environments, rainy season 1984.

Identity	Pedigree	Pod yield (kg ha^{-1})			
		ICRISAT		Bhavani-sagar	Mean
		HI[1]	LP		
HYQ(CG)S14	[(Robut 33-1 x NC Ac 2821) x NC 3033)]$F_{10}B_1$	5210	1550	2370	3040
HYQ(CG)S3	(M 13 x Robut 33-1)$F_{15}B_1$	5730	1160	1750	2880
HYQ(CG)S5	(Robut 33-1 x M 13)$F_{15}B_1$	5010	1370	2250	2880
HYQ(CG)S1	(JH 335 x Robut 33-1)$F_{14}B_1$	4880	1300	2080	2750
HYQ(CG)S2	(M 13 x Robut 33-1)$F_{15}B_1$	4940	1330	1800	2690
Controls					
ICGS 6[2]		5160	950	1860	2660
Robut 33-1[2]		4400	1160	1760	2440
SE		±282	±129	±252	
Trial mean (n=64)		5050	1250	1970	
CV (%)		10	18	22	

1. HI = High-input conditions, LI = Low-input conditions, see Table 10 footnotes 1 and 2.
2. Small-seeded control cultivars.

However, this is complicated in groundnut, because of its indeterminate nature, and because pod maturation is a cumulative, subterranean process. Maturity determinations are further complicated by soil and atmospheric factors. Therefore, we worked on an operational definition for maturity in groundnut.

We used a 'staggered-harvesting system' in which the lines under evaluation are harvested at predefined regular intervals from randomized and replicated field plots. Pod and sound mature kernel (SMK) yields, shelling percentages, and kernel masses are estimated from the staggered harvests. Maturity is determined as that point of time when these maturity-related characters reach their peak. Preliminary experience has indicated that this is a useful system to define agronomic maturity in groundnuts.

Using this approach, we screened 60 breeding lines for maturity in the 1983/84 postrainy season, and 184 breeding lines and 71 germplasm lines in the 1984 rainy season, in nine trials. From the two postrainy-season trials, we retained 44 lines for retesting in the rainy season. From the breeding lines tested in six trials in the rainy season, we selected 26 early-maturing (90-100 days) and 22 extra-early-maturing lines (75 days). The performance of four selected lines is compared to the controls in the staggered harvests from one trial in Table 28. The results show that the early-maturing lines, unless otherwise harvested early, do not exhibit significant advantages. This is, perhaps, because of a positive regression of yield on maturity and the losses that occur after maturity.

The progress of SMK yield ha^{-1} over the harvests of two early varieties and three controls is given in Figure 13. ICGS(E) 71 appeared to be an extra-early line, maturing in less than 75 days, and consistently out-yielding Chico, also from the same group. ICGS(E) 61, that showed the highest yield in 90 days also showed superiority when harvested at 75 days. All the selections are being retested.

In the rainy season we also screened 75 germplasm lines obtained by increasing single-plant selections from early-maturing germplasm accessions (ICRISAT Annual Report 1984,

Table 28. Performance of selected early-maturing groundnuts in staggered harvests at 75, 90, 105, and 120 DAS under high-input conditions[1], ICRISAT Center, rainy season 1984.

ICGS(E) number	Pedigree	Pod yield (kg ha^{-1})	SMK yield (kg ha^{-1})	Shelling (%)	100-kernel mass (g)
		---75DAS---			
11	(X14-X-X-1-B x Goldin 1)	3370	1940	66	41
21	(72 R x Chico)	3290	1901	67	44
22	(Ah 65 x Chico)	3540	1890	64	38
27	(JH 89 x Chico)	3260	1560	59	36
Controls					
Chico (Early source line)		2100	1200	65	30
JL 24 (National)		2670	1280	55	41
Robut 33-1 (National)		2840	1450	61	35
SE		±301	±214	±4.4	±3.5
Trial mean (n = 33)		2950	1580	61	37.0
CV (%)		13	17	9	12
		---90DAS---			
11	(X14-X-X-1-B x Goldin 1)	3490	1930	65	40
21	(72 R x Chico)	3530	1910	63	38
22	(Ah 65 x Chico)	3320	1850	63	40
27	(JH 89 x Chico)	3930	2490	68	41
Controls					
Chico (Early source line)		2490	1400	63	27
JL 24 (National)		3240	1730	59	44
Robut 33-1 (National)		3240	1820	64	39
SE		±358	±329	±7.7	±3.1
Trial mean (n = 33)		3330	1780	63	38
CV (%)		13	23	15	10
		---105 DAS---			
11	(X14-X-X-1-B x Goldin 1)	2760	1260	59	32
21	(72 R x Chico)	3090	1720	68	38
22	(Ah 65 x Chico)	3350	1860	62	32
27	(JH 89 x Chico)	2890	1590	65	37
Controls					
Chico (Early source line)		1400	620	47	24
JL 24 (National)		2960	1780	66	40
Robut33-l (National)		2760	1610	66	37
SE		±444	±336	±5.7	±2.1
Trial mean (n = 33)		3120	1710	63	35
CV (%)		17	24	11	7

Continued.

Table 28. *Continued.*

ICGS(E) number	Pedigree	Pod yield (kg ha^{-1})	SMK yield (kg ha^{-1})	Shelling (%)	100-kernel mass (g)
		--------120 DAS--------			
11	(X14-X-X-1-B x Goldin 1)	2930	1590	64	45
21	(72 R x Chico)	2680	1820	72	45
22	(Ah 65 x Chico)	2610	1700	73	40
27	(JH 89 x Chico)	2420	1440	67	46
Controls					
Chico (Early source line)		1220	470	45	32
JL 24 (National)		2420	1450	67	51
Robut 33-1 (National)		2960	1950	71	53
SE		±347	±276	±5.4	±3.4
Trial mean (n = 33)		2530	1500	66	42
CV (%)		17	23	10	10

1. See Table 10 footnote 1.

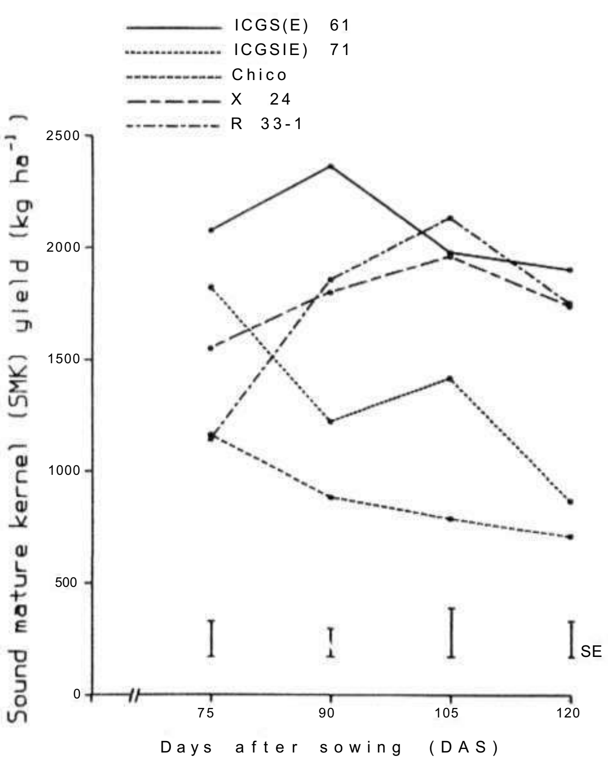


Figure 13. Sound mature kernels (SMK) yield (kg ha^{-1}) of two breeding and three control groundnut lines in staggered harvesting under high-input conditions, ICRISAT Center, rainy season 1984.

pp.212) by staggered harvests, and we identified 13 selections with high, early yields for further testing for earliness and yielding ability. Eight of these lines are valencias.

In the rainy season, we also tested 64 early-maturing breeding lines in two trials at five locations in India to determine their adaptability and yield stability across locations. We selected 18 early lines for their superior performance (Table 29).

In 1984 we organized an International Groundnut Early-Maturing Cultivar Trial with 32 entries, and sent it to 12 locations; 6 in Africa, 2 in Asia, and 3 in other continents.

We continued our crossing work to include newly-identified, early-maturing lines, and high-yielding but late-maturing lines with other useful traits.

Utilizing Wild *Arachis* Species

We continued to backcross interspecific derivatives. We selected disease-resistant segregates from segregating populations of stable, tetraploid, interspecific derivatives, and advanced them in single-plant progeny rows. Advanced

Table 29. Performance of selected early groundnut lines at five locations in India, rainy season 1984.

		Pod yield (kg ha^{-1})					
ICGS(E) number	Pedigree	ICR1SAT (HI)[1](90)[2]	ICRISAT (LI)[1](114)	Bhavani-sagar (85)	Dharwad (98)	Hisar (107)	Mean
Trial 31							
21	(72R x Chico)	3530	1100	1710	2830	3660	2566
10	(JH 171 x Chico)	3480	1160	1220	2640	3850	2470
8	(NC Ac 17113 x TG 16)	3490	1010	1420	2490	3930	2468
26	(Tifspan x 28-206)	3280	1170	1370	2600	3590	2402
13	(Jacana x L.No.95 A)	3270	1060	1150	2880	3520	2376
12	(148-7-4-3-12-B x 72 R)	3490	880	1680	2100	3350	2300
Controls							
Chico (Early source line)		2490	330	1230	2280	2310	1728
JL 24 (National)		3240	1090	1000	2670	2790	2158
Robut 33-l(National)		3240	1250	861	2840	2590	2156
SE		±353	±144	±275	±275	±538	
Trial mean (n=33)		3330	1030	1200	2680	3140	
CV (%)		13	17	28	13	21	
Trial 32							
56	(ICGS 44 x TG 2E)	4280	900	1230	3800	5650	3172
55	(ICGS 22 x TG 2E)	4050	1080	1190	4060	4540	2984
34	(2-5 x Robut 33-1)	3970	950	1750	3870	3720	2852
52	(Shantungku No. 203 x Robut 33-1)	4220	1390	3950	3410	2814	
50	(Goldin 1 x Faizpur 1-5)F_8 x L.No.95 A	4270	790	940	3560	4470	2806
38	(X52-X-X-3-B x Chico)	3810	1050	1140	3650	4020	2734
30	(Ah 65 * Chico)	3670	1140	1430	4010	3250	2700
49	(Gangapuri * L.No.95 A)	3720	890	1130	3670	4040	2690
36	(TMV 7 x Chico)	3150	1150	1120	4060	3950	2686
53	[(HG 1 x EC 76446(292)F_8) x Robut 33-1-1-10-3 F_4]	3600	900	1050	4350	3130	2606
48	(FSB 7-5 x L.No.95 A)	3560	770	1070	3290	4320	2602
Controls							
Chico (Early source line)		1920	270	770	1190	2310	1292
JL 24 (National)		3210	690	700	3800	3130	2306
Robut 33-1 (National)		3190	780	1090	3480	3460	2400
SE		±355	±184	±248	±349	±467	
Trial mean (n=33)		3430	850	1080	3510	3620	
CV (%)		13	26	28	12	16	

1. See Table 10 footnotes I and 2.
2. Figures in parentheses are days from sowing to harvest.

selections from interspecific derivatives were grown in replicated trials at ICRISAT Center and Bhavanisagar, to confirm resistance to rust and late leaf spot, and to characterize their agronomic traits. Certain accessions reported to be resistant to foliar diseases and/or bud necrosis disease *(A. correntina, Arachis* species 30007, *Arachis* species 30011, and *Arachis* species 30035) were cytogenetically analyzed and used in the crossing program.

Cytogenetic Investigations

After preliminary karyomorphological analysis (ICRISAT Annual Report 1983, p. 213) new accessions have been hybridized with the two known diploid species of section *Arachis, A. batizocoi*, (the only representative of the B genome) and *A. cardenasii* (representative of the A genome). The new accessions have also been hybridized as male parents with cultivars *of A. hypogaea* (ICRISAT Annual Report 1983, p.214). From these crosses, we cytologically analyzed four diploid and three triploid hybrids. Near-normal bivalent association and pollen fertility in the F, hybrid between *A. cardenasii* and *Arachis* species 30035 (Table 30) suggests that the two taxa are phylogenetically close. A significantly lower frequency of bivalent associations and higher frequency of univalents in the F_1 hybrids, *A. batizocoi* x *Arachis* species 30017 and *Arachis* species 30011 x *A. batizocoi* (Table 30), suggests that these taxa are distantly related to the B genome of section *Arachis,* In spite of a nearly-normal bivalent association, the hybrid between *A. cardenasii* and *Arachis* species 30007 had poor pollen fertility indicating cryptic structural differences between the genomes of these two taxa (Table 30). However, on morphological and karyomorphological grounds, *Arachis* species 30007 belongs to section *Erectoides.*

The chromosome-pairing behaviour in triploid hybrids between *A. hypogaea* and the three diploid accessions, *A rachis* species 30069, 30017, and 30011 (Table 31) is comparable to previously-obtained triploid hybrids between *A. hypogaea* and the A genome diploid species, suggesting that the investigated diploid taxa are constituted by the A or a closely-related genome.

Crosses between a few old and new accessions of section *Arachis* and *A. hypogaea* have again been attempted this year in order to; obtain triploid hybrids, estimate the percentage of immature ovules produced because of incompatibility reactions, and determine the ploidy levels of seedlings obtained by rescuing such underdeveloped embryos (Table 32).

Production of Breeding Lines

Further backcrossing of backcross derivatives, or advancement by selfing, resulted in the pro-

Table 30. Chromosome association in F_1 hybrids between old and new diploid accessions of section *Arachis.*

Cross	Chromosome association				No. of cells analyzed	Pollen fertility (%)
	I	II	III	IV		
A. batizocoi x *Arachis* sp 30017	5.5	6.6	0.3	0.1	25	-
SE	±0.44	±0.24	±0.09	±0.10		
Arachis sp 30011 x *A. batizocoi*	5.9	6.9	0	0.1	20	-
SE	±0.55	±0.29		±0.05		
A. cardenasii x *Arachis* sp 30035	0.1	9.9	0	0	24	97
SE	±0.08	±0.04				
A. cardenasii x *Arachis* sp 30007	0.5	9.4	0.1	0.1	25	39-43
SE	±0.17	±0.22	±0.11	±0.04		

Table 31. Chromosome association in hybrids between *A. hypogaea* (4x) and some new diploid accessions of *Arachis.*

Cross	Chromosome association				No. of cells analyzed	Pollen fertility (%)
	I	11	III	IV		
A. hypogaea x *Arachis* sp 30069	8.1	9.8	0.5	0.2	14	-
SE	±0.52	±0.33	±0.17	±0.11		
A. hypogaea x *Arachis* sp 30017	6.6	8.9	1.3	0.4	24	8
SE	±0.39	±0.43	±0.27	±0.1		
A. hypogaea x *Arachis* sp 30011	8.4	9.2	0.9	0.1	31	11-30
SE	±0.56	±0.29	±0.18	±0.05		

duction of 13 more stable, fertile, tetraploid interspecific derivatives. Of these 4 were from the triploid-hexaploid route, 8 from the amphiploid route, and 1 from the autotetraploid route.

Sixty advanced selections and a large number of segregating selections from interspecific derivatives involving *A. cardenasii* and *A. bath zocoi* x *Arachis* species GKP 10038 were sown in the 1982/83 postrainy season for advancement. They were classified into groups according to their disease reactions and habit, and sown at ICRISAT Center and Bhavanisagar. An effort was made to screen out undesirable segregates, and to attain genotypic and phenotypic unifor-

Table 32. Number of pollinations, percentages of pegs, pods, and seeds developed in crosses between the cultivars of two subspecies of *A. hypogaea* and wild diploid *Arachis* species, ICRISAT Center, rainy season 1984.

Cross	Pollinations	Pegs formed (%)	Pod set (%)	Pods with mature seeds (%)	Immature pods (%)	Mature pods with immature ovules	Ovules embryo-cultured[1]
A. hypogaea ssp *fastigiata* (Spanish)							
Arachis sp 30007	131	33	16	3	0.8	12	25
Arachis sp 30017	153	33	28	21	0.7	7	29
Arachis sp 30035	202	37	29	26	-	3	18'
A. correntina	157	47	24	15	-	9	19
A. batizocoi	125	36	30	2	8	2	56
Arachis sp GKP 10038LL	162	35	30	10	6	15	64
A. eardenasii	27	22	22	7	4	11	6
Arachis sp HLK 410	125	30	25	11	2	12	36
A. hypogaea ssp *hypogaea* (Virginia)							
Arachis sp 30007	55	49	40	0	-	40	24
Arachis sp 30017	55	46	40	31	6	4	22
Arachis sp 30035	34	44	38	35	-	3	2
A. correntina	29	14	4	0	4	-	2
A. batizocoi	76	36	26	0	-	26	31
A. chacoense	56	39	18	II	5	2	7
Arachis sp GKP 10038LL	44	41	36	2	2	32	29
Arachis sp HLK 410	32	38	31	9	-	22	12

1. One normal ovule did not survive from the cross ICGS 26 x *Arachis* sp 30035.

mity. Several controls were used, of which two (Robut 33-1 and TMV 2) are local, high-yielding, released cultivars, two (EC 76446, NC Ac 17133 RF) are reportedly-resistant germplasm lines, and one (FDRS 10) a resistant breeding line.

These experiments resulted in the selection of 28 lines resistant to both late leaf spot and rust, with comparable or higher yield than the best controls at both locations, three lines resistant to late leaf spot, and with comparable or higher yield than the best control, and another three lines with resistance to rust, and comparable or higher yield than the best control (Tables 33-35).

These lines have expressed either a higher degree of resistance or a hypersensitive reaction against the two pathogens. For example, lines such as CS 9, CS 30, 2408/1, and 850/1 deve-

Table 33. Disease reaction for leaf spot and rust, and pod and haulm yields (kg ha^{-1}) of some of the advanced selections from *A. cardenasii* interspecific derivatives sown in 8 x 8 lattice designs. ICRISAT Center and Bhavanisagar, rainy season 1984.

	Late leaf spot score[1]		Rust score[1]	Pod yield (kg ha^{-1})		Haulm yield ICRISAT
Identity	ICRISAT	Bhavanisagar	ICRISAT	ICRISAT	Bhavanisagar	(kg ha-*)
Lines resistant to late leaf spot and rust						
CS 9	2.9	4.8	3.0	5040	1070	8230
CS 30	3.4	5.0	2.0	4890	940	10060
CS 22	3.8	5.4	3.0	5010	1240	8680
CS 62	3.5	4.5	2.0	4470	980	8180
CS 31	3.5	4.4	2.0	4580	1280	8630
CS 33	3.7	4.6	1.7	4220	1310	9880
CS 26	3.7	4.0	2.0	4520	1700	8600
CS 36	3.8	5.0	1.4	4430	1400	8690
CS 25	4.7	4.9	2.3	3720	1560	7480
803	5.0	5.3	3.0	4530	1600	7150
Lines resistant to late leaf spot						
CS 39	4.3	5.0	6.0	3660	890	6760
Lines resistant to rust						
CS 2	8.0	9.0	1.7	3440	440	5590
CS 14	6.0	7.5	2.3	4490	1070	7200
CS 19[2]	7.8	8.6	1.7	2720	490	4840
Controls						
EC 76446 (292)3	6.0	7.1	2.7	4160	910	7480
NC Ac 17133-RF[3]	6.5	7.4	8.0	4600	760	5680
Robut 33-1[4]	9.0	8.9	9.0	2690	390	3260
TMV 2[4]	9.0	9.0	9.0	2320	120	3990
SE	±0.4	±0.4	±0.7	±253	±161	±522
CV (%)	13.2	9.2	31.2	10.8	28.3	12.1

1. Mean of field disease scored on a 1-9 scale, where 1 = no disease and 9 = 50-100% foliage destroyed.
2. *A. hypogaea x (A. batizocoi x Arachis* sp GKP 10038) interspecific derivatives.
3. Reported foliar disease-resistant germplasm line.
4. Foliar disease-susceptible high-yielding released cultivars.

Table 34. Disease reaction for late leaf spot and rust, and pod and haulm yields (kg ha^{-1}) of some of the best selections from *A. cardenasii* interspecific derivatives segregating for leaf spot resistance, sown in 8 * 8 lattice designs, ICRISAT Center and Bhavanisagar, rainy season 1984.

	Late leaf spot score[1]		Rust score[1]	Pod yield (kg ha^{-1})		Haulm yield ICRISAT (kg ha^{-1})
Identity	ICRISAT	Bhavanisagar	ICRISAT	ICRISAT	Bhavanisagar	
Lines resistant to rust and late leaf spot						
820	4.3	4.3	2.7	5020	1670	7780
2245	4.2	4.8	1.9	4050	1100	7410
838	5.0	4.4	2.5	4240	1100	7110
2403	3.3	5.6	1.6	3600	1150	6150
886/1	4.1	5.7	2.1	3510	1310	7780
820/1	3.5	4.6	2.7	4100	1430	6450
2133	3.6	5.3	3.9	4710	1160	6300
848	3.8	4.1	2.2	3700	980	8000
2404/2	4.1	5.0	3.6	3980	1420	6670
2118/1	4.6	4.7	5.1	3710	1200	8150
Lines resistant to rust						
888	5.3	6.0	2.3	3530	780	8000
Controls						
EC 76446(292)2	6.7	8.1	2.5	2310	1060	5930
NC Ac 17133-RF[2]	6.3	7.1	6.6	3850	690	5260
Robut 33-1[3]	9.0	9.0	9.0	2440	390	3260
TMV 2[3]	8.9	9.0	9.0	1680	230	7110
SE	±0.4	±0.3	±0.6	±367	±155	±1075
CV (%)	10.8	8.5	23.4	18.5	25.3	21.5

1. Mean of field disease scored on a 1-9 scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.
2. Reported foliar disease-resistant germplasm lines.
3. Foliar disease-susceptible high-yielding released cultivars.

loped a few small late leaf spot lesions with poor sporulation and no defoliation. On the other hand, lines such as CS 2, CS 19, 845, 2403, 886/1, and 888 had very few small nonsporulating rust pustules. We are attempting to characterize these lines for entry in the All India Coordinated Research Project on Oilseeds (AICORPO) trials or for release as new germplasm lines.

Barriers to Hybridization

Four *A. hypogaea* cultivars, Robut 33-1, MK 374, TMV 2, and M 13 were used as female parents in crosses with certain accessions of section *Rhizomatosae*. These crosses were in conjunction with single- or sequential- hormone applications. From the pods obtained, ovules were cultured on liquid media (Table 36), and later the embryos from them were dissected for culture (Table 37). The dissected embryos often proliferated into callus and developed shoots. We successfully grafted these small shoots onto cultivated groundnut seedling stocks. Some of the cultured ovules allowed preferential growth of the embryos within them, and the consequential emergence and growth of the latter out of the ovules.

Table 35, Disease reaction for late leaf spot and rust, and pod and haulm yields (kg ha^{-1}) of some of the best selections from segregating populations of *A. cardenasii* derivatives sown in 8 x 8 triple lattice designs. ICRISAT Center and Bhavanisagar, rainy season 1984.

Identity	Late leaf spot score[1]		Rust score[1]	Pod yield (kg ha^{-1})		Haulm yield ICRISAT (kg ha^{-1})
	ICRISAT	Bhavanisagar	ICRISAT	ICRISAT	Bhavanisagar	
Lines resistant to rust and late leaf spot						
850/1	4.7	5.0	2.0	4990	1420	7310
2408/1	4.3	5.4	2.7	5230	1220	6410
856	4.7	5.0	2.7	4640	1270	5460
821/1	4.9	5.0	2.7	3280	1340	7340
965	4.7	5.7	2.0	4580	1220	6470
2241	4.7	5.7	2.3	3800	940	7360
799	4.9	5.7	2.3	3990	1090	7190
845	4.8	5.3	2.3	4740	930	6100
Lines resistant to late leaf spot						
943	4.4	4.7	7.3	2850	1180	5430
Controls						
EC 76446 (292)[2]	6.6	8.2	3.3	4110	700	4110
NC Ac 17133-RF[2]	7.6	8.2	7.0	4810	720	4060
FDRS 10[3]	8.0	8.0	4.0	4310	570	6010
Robut 33-1[3]	8.8	9.0	8.7	3500	360	2140
TMV 2[3]	8.7	8.8	8.7	2500	160	3720
SE	±0.4	±0.4	±0.7	±322	±133	±696
CV (%)	12.0	9.0	20.1	14.5	25.7	21.0

1. Mean of field disease scored on a 1-9 scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.
2. Reported foliar disease-resistant germplasm lines.
3. Foliar disease-susceptible high-yielding released cultivars.

Table 36. Number of pods harvested, ovules cultured, and responsive ovules from *A rachis hypogaea x Arachis sp* 10563.

Cultivar	Pods[1] harvested	Ovules cultured in liquid medium	Cultured ovules lost due to contamination	Responsive ovules
A. hypogaea				
MK 374	419	449	157	130
M 13	52	93	18	11
TMV 2	264	277	55	114
Robut 33-1	14	16	3	5

1. From various hormone applications.

Table 37. Number of embryos dissected from ovules precultured on liquid media, and number of responsive embryos (on MS with NAA 0.5 mgL^{-1} and BAP 0.5 mgL^{-1}) from *Arachis hypogaea x Arachis* sp 10563.

Cultivar	Embryos cultured	Embryos lost due to contamination	Embryos growing
MK 374	147	14	76
TMV 2	86	17	26
Robut 33-1	34	3	13

Pegs obtained from gibberellin-treated Robut 33-1 x *A. pusilla* crosses were retreated with five concentrations of indolyl acetic acid on different days after pollination, but pod set was not satisfactory.

Attempts were also made to use two accessions, *Arachis* species 9797 and *Arachis* species 10563 of section *Rhizomatosae* as female parents, and *A. hypogaea* cv MK 374 as a male parent. Pegs and pods were recorded with or without the gibberellin applications. Table 38 shows that even in these crosses gibberellin application promotes peg and pod development. We cultured the resulting immature ovules.

Distribution of Material

The interspecific derivatives are in great demand. We have supplied several lines on request to three centers in the Peoples' Republic of China, and to one center each in Peru and the USA. A selection, CS 30, has been supplied to AICORPO for use in their rust-resistance breeding program. ICRISAT breeders are also using several of these lines in various projects.

Table 38. Peg and pod production *in Arachis* sp 9797 (section *Rhizomatosae) x A. hypogaea* cv MK 374.

Postpollination treatment	Pollinations	Pegs	Pods peg-'
None	43	3	0
Gibberellic acid (87.5 mg L^{-1})	181	33	15.15
Gibberellic acid (44 mg L^{-1})	27	3	0
Kinetin (10 mg L^{-1})	27	2	0
Naphthalene acetic acid (25 mgL^{-1})	28	3	3

International Cooperation

Cooperation with AICORPO

Coordinated Yield Trials

ICRISAT Center trials. During the 1984 rainy season we conducted nine yield trials, sponsored by AICORPO, on Alfisols at ICRISAT Center. There were 28 entries in the Initial Evaluation Trial for Spanish bunch cultivars (IET-SB), and the ICRISAT entry ICGC(PRS) 1 was ranked 1st, yielding 1823 kg pods ha^{-1}, compared to the national control JL 24 that yielded 1227 kg ha^{-1}. In the IET for Virginia bunch cultivars (IET-VB) four cultivars, including three ICRISAT entries, ICG(PRS) 3, ICGS 66, and ICGS 50, outyielded all three controls. ICG 2271, a multiple-pest resistant entry, was the highest yielder (2384 kg ha^{-1}) in the IET for Virginia runner cultivars (IET-VR).

ICGS 31 gave the highest yield in the Coordinated Varietal Trial for Spanish bunch cultivars (CVT-SB), significantly outyielding the national control, JL 24, but not the local control, Robut 33-1. ICGS 56 gave the highest yield in the CVT for Virginia bunch cultivars (CVT-VB), but was not significantly better than the minikit control, C 198. ICGS 6 was the highest-yielding entry in the National Elite Trial for Virginia bunch cultivars (NET-VB), significantly outyielding the minikit control cultivar C 198. In the Foliar Diseases Resistant Varietal Trial (FDRVT) eight ICRISAT lines were the top yielders. ICG(FDRS) 11 yielded 1823 kg ha^{-1} compared to 868 kg ha^{-1} by JL 24, and 1487 kg ha^{-1} by Robut 33-1.

Multilocational Trials

Rainy-season trials. During the 1983 rainy season ICGS lines were tested in the AICORPO trials systems in various ecological zones. Several lines were promoted to the next stage of testing and many new entries were submitted for the 1984 rainy season at the AICORPO Workshop held at Coimbatore in April. The current status of ICRISAT material in the AICORPO rainy-season system is shown in Table 39.

Table 39. Current status of ICRISAT entries in AICORPO rainy season zones, 1984.

Trial[1]	Entry	Zone
IET(VB)	ICGS 54,56	1
	ICGS 50,54,56	4
	ICGS 50,54	5
	ICGS 62,63,64,65,66, ICGSPRS 3	1,2,3,4,5,6
CVT(VB)	ICGS 18,20,46,47,49	1
	ICGS 48,49	3
	ICGS 18,49	4
	ICGS 46,47,56	5
	ICGS 46,48	6
NET(VB)	ICGS 4,5,6	1,5
	ICGS 4,6	4
IET(SB)	ICGS 35-1	1,4,6
	ICGS 44-1	1,2,3,4
	ICGS 57	4,5
	ICGS 51	5
	ICGSPRS 1,2, ICGS 67	1,2,3,4,5,6
CVT(SB)	ICGS 2,3	1
	ICGS 11	1,2
	ICGS 21	2
	ICGS 26	4,5
	ICGS 30,35-1	2,5
	ICGS 44-1	5,6
	ICGS 51	2,3,4
	ICGS 57	1
NET(SB)	ICGS 1	1

1. IET = Initial Evaluation Trial
CVT = Coordinated Varietal Trial
NET = National Elite Trial
SB = Spanish bunch
VB = Virginia bunch.

Postrainy-season trials. ICGS 11 performed well in it's first year of minikit (prerelease) testing and was retained for a final evaluation in the 1983/84 postrainy season in Zones 3 and 5. It gave yield increases over SB-XI (national control) in 1982/83 ranging from 16 to 110% in Zone 3. In the CVTs in Zone 2 ICGS 44 was outstanding, and along with ICGS 21, was promoted to the National Elite Trial (NET). ICRISAT entries in the CVT were ranked 1st and 2nd, in Zone 2, 2nd in Zone 3,1 st and 2nd in Zone 5, and 1st, 2nd, and 3rd in Zone 6. In the NET, ICRISAT entries were ranked 3rd in Zone 2, 1st, 2nd, and 3rd in Zone 3, 2nd and 3rd in Zone 5, and 1 st and 3rd in Zone 6.

The current status of ICRISAT's material in the AICORPO postrainy-season testing is shown in Table 40.

Distribution of Breeding Material and Trials

We again dispatched breeding lines to cooperators in many countries. During the year we finalized plans and entries for three new international trials involving early-maturing lines, large-seeded confectionery cultivars, and advanced breeding lines with resistance to foliar diseases.

Table 40. Current status of ICRISAT entries in AICORPO postrainy (rabi/summer) season trials, 1983/84.

Trial	Entry[1]	Zone
IET(Set II)	ICGPS 8	1,2,3,4,5,6
	ICGS 68	1,2,3,4,5,6
	ICGS 71	1,2,3,5
	ICGS 75,77	1,2,3,4,5,6
	ICGS 81	1,2,3,5,6
	ICGS 82	1,2,3,4,5,6
CVT	ICGS 21,44	3,4,5,6
NET	ICGS 21,44	2
Minikit	ICGS 11	3,5

1. All postrainy entries are SB (spanish bunch types).

Regional Program for Southern Africa

The ICRISAT Regional Groundnut Improvement Program for Southern Africa, based at the Chitedze Agricultural Research Station, Lilongwe, Malawi was established in 1982 with one plant breeder. A pathologist was recruited in 1984. The program aims to develop high-yielding breeding lines and populations adapted to the region, with resistance to factors limiting production by small scale farmers. Breeding for resistance to the major diseases in the region receives top priority.

Weather at Chitedze. Rainfall was very similar to the 1982/83 season, 683 mm from December 1983 to May 1984, but this year the distribution was less favorable. Rains were later, and there were characteristic dry spells in January, the latter half of March, and from 4th April onwards. Total rainfall in April was only 13.1 mm compared to 42.5 mm in the previous season.

Growing conditions. Soils in the groundnut fields were sampled in June 1983. The pH was 5.5 and available phosphorus was low (3.58 ppm). In the absence of dolomitic lime, only P_2O_5 at 40 kg ha^{-1} and gypsum at 400 kg ha^{-1} were applied. Alachlor (Lasso®), applied before emergence at 4 L ha"^{1}, gave good weed control for approximately 30 days. Only the hybridization block and F, plants received standard plant protection measures to control aphids and leaf spots. All trials were sown on 60 cm ridges at an in-row spacing of 10 cm.

Diseases and Pests

Fungal Diseases

Disease development was similar in the 1983/84 and 1982/83 seasons. Early leaf spot appeared 2 weeks after emergence and rapidly assumed epidemic proportions. The incidence of rust and late leaf spot was low and they only appeared later, when early leaf spot had already caused heavy defoliation.

Groundnut plants devastated by early leaf spot *(Cercospora arachidicola)* infection, Bvumbwe, Malawi, 1983/84.

Early leaf spot (*Cercospora arachidicola*). Using the trap plants from our rosette study (see Virus Diseases) we found that spore levels were low to very low until 20 February, some 40 days after field emergence of the crop. After a relatively small increase in lesions on exposed plants there was a sudden and dramatic increase following a period of rain. A peak was reached between 2-6 March. There followed an equally dramatic decline, possibly following massive defoliation of the field-grown crop. This monitoring could lead to a more rational approach to fungicide application.

Late leaf spot (*Cercosporidium personatum*) and rust (*Puccinia arachidis*). These diseases were first recorded in early March at very low levels. Late leaf spot levels remained low throughout the season but rust reached higher levels, 36 pustules plant"^{1}, during exposure between 19-24 April. The late build-up of rust, as the plants near maturity, confirms the general view that rust is not a problem on the Lilongwe Plain.

Virus Diseases

Rosette cultures. Typical chlorotic rosette was collected from the field and a culture was established in the greenhouse on the cultivar Spancross. An efficient culture of the vector, *Aphis craccivora,* was also established and similarly maintained. A culture of non-viruliferous aphids was derived and maintained in isolation. We obtained a series of standard virus-indicator plants through official plant quarantine channels. Germination was generally good but *Nicotiana benthamiana* and *Chenopodium amaranticolor,* diagnostic test-plant hosts of rosette, proved difficult to maintain satisfactorily, probably due to high greenhouse temperatures. Efforts are being made to overcome these problems.

Disease monitoring. We assessed the feasibility of using bait or trap plants to monitor disease presence, development, and intensity throughout the growing season. Ten 21-day old greenhouse-grown Spancross seedlings were exposed in the field every 3 to 5 days between 30 January and 25 June 1984. Numbers of *A. craccivora* alates, apterae, and nymphs were recorded at the end of each exposure period, the plants were then sprayed with insecticide and returned to the greenhouse. They were subsequently scored for rosette and PMV.

Aphids were consistently found on the exposed plants throughout February and March, but the numbers then declined sharply and infestation became sporadic. The highest numbers were recorded from 30 January to 16 February. Two minor peaks occurred from 12 to 29 March, and 24 April to 7 May. The latter period probably coincided with emigration from the mature groundnut crop to other hosts.

Analysis of seasonal epidemics. Although rosette is important throughout the region, devastating epidemics are sporadic. We cannot therefore rely on natural incidence for annual screening. Late sowing enhances incidence, but not sufficiently in years when infection levels are very low. We therefore carefully monitored disease incidence during the growing season to better understand features of natural occurrence. Three contiguous plots, each measuring 200 * 85 m with their long axes aligned east-west, were subdivided into 6 x 6 m plots to give some 400 plots block^{-1}. Sowing took place in the middle of December and plants emerged from 28-31 December. Rosette was first recorded on 18 January and observations indicated only 12 primary infections, representing 10 primary foci. The primary foci were scattered and appeared to be at random. Overall incidence of rosette was about 1% in 1983/84. The mean rosette incidence for plots containing a primary incidence was 38.3%, for adjacent plots 6.3%, and for outer plots 0.4%. Disease gradients associated with primary foci were therefore exceptionally steep, falling off by a mean factor of about 6 within a radius of 6 m of that source, and by a mean factor of about 100 within a radius of 9 m from the source.

Seasonal origins. We started to study wild hosts of *A. craccivora* as possible reservoirs of the virus. Five important aphid hosts and nine other species, all herbaceous or woody herbaceous plants, were shown not to be hosts of the virus. The search has now shifted to tree species.

A regional program has been initiated to study the ecology of the vector and virus. Two sites have been chosen to study in detail the effects of direction and speed of local surface winds and upper-level air flows on vector migrations. Another cooperative program will study the role of groundnut volunteer plants surviving the dry season in rosette carry-over. No volunteer plants were found in a limited survey carried out in the southern region of Malawi.

Peanut mottle virus (PMV). Infections on trap plants took place between 13 February and 15 March. The overall incidence on trap plants was 8%, higher than on the standing field crop. This is possibly because young trap plants are more susceptible to the virus, more attractive to the vector, or merely express symptoms more readily than older plants.

Insect Pests

Hilda patruelis. *Hilda* is a polyphagous sucking bug associated with a severe wilt in groundnut. The pest is present throughout the region and although the incidence of wilt is generally low, there are areas where devastating local damage occurs. It has been assumed that *Fusarium* spp enter feeding punctures and cause the wilting symptom. We made laboratory tests on the effects of *Hilda* feeding on germinating seedlings, grown in petri-dishes. Four to six insects were introduced into the dishes when the radicles were 4-5 cm long. After 5 days, control seedlings were growing normally but plants fed on by *Hilda* showed a dramatic and massive collapse of tissue 1-2 cm below the hypocotyl. Existing lateral roots were discolored and many collapsed. Growth of new lateral roots was inhibited. The tests were repeated with the same results. Further studies are in progress.

Plant Improvement

Germplasm Accessions

We recieved 108 new introductions, mostly of South American origin from ICRISAT Center, and we evaluated them, together with 162 previously-introduced lines, in non-replicated plots with repeated controls of six standard cultivars from the region, Mani Pintar, Egret, RG 1, SAC 58, Chalimbana, and Spancross; and three cultivars from India, J 11, JL 24, and Robut 33-1. Of the 270 entries, 70 yielded more than the highest-yielding control. Of these 70,38 were Virginia types, and 32 were early-maturing Spanish and Valencia types. Many entries had a 100-seed mass greater than 50 g, and if they maintain their performance, will have ready acceptability, particularly for confectionery purposes. We rated entries visually for early leaf spot, but they were all heavily defoliated before harvest. We evaluated morphological traits, assigned ICRISAT Groundnut Malawi (ICGM) numbers to entries, and entered them in the germplasm register.

Fifty-one germplasm lines and elite parents, selected on their 1982/83 performance, were evaluated with standard controls. Five Spanish entries, ICGM 286, 281, 284, 177, and 197 significantly outyielded Sellie, the highest-yielding Spanish cultivar. Their yields, however, were not significantly different from that of the highest-yielding Virginia control cultivar, Egret. The Virginia cultivars ICGM 285 and ICGM 336 significantly outyielded Mani Pintar, a recommended Virginia cultivar in Malawi. ICGM 336, 177, and 197 had also yielded well in the 1982/83 trial.

Under Chitedze conditions the cultivar Chico, used extensively at ICRISAT Center as a very early-maturing parent, took 5-7 days longer to mature than other Spanish types.

For the 1984/85 season, new cultivars and 21 wild *Arachis* species will be evaluated. ICGM lines and 54 pest- and disease-resistant lines are being multiplied for seed increase. We sowed a 53-entry replicated preliminary, and a 24-entry advanced germplasm evaluation trial. An elite germplasm trial, consisting of the best 24 entries from the advanced trial and 12 control cultivars, was also planted.

Hybridization

Ninety-six crosses, involving indigenous and exotic cultivars, were attempted in two different sets in the field. Parents included rosette-resistant cultivars RG 1, RMP 93, and RRI 6; foliar disease-resistant selections 1CGMS 27 and 28; and a larger-seeded cultivar, E879/6/4. The low crossing success rate of 8.4% was attributed to the dry weather and plant deaths following attack by *Hilda patruelis.* Effective rainfall ceased in the middle of March and led to the failure of pod development in many of the hybrid pegs. Access to an irrigation facility would have considerably improved the situation.

An average crossing success rate of 24% was achieved in a greenhouse crossing program when a 6 x 6 diallel was attempted using rosette-resistant lines and high-yielding susceptible entries. Seeds cross^{-1} ranged from 3 to 69.

In the 1984/85 season we will attempt 132 crosses in the field, and 76 in the greenhouse.

Breeding for Disease Resistance

Foliar fungal diseases. Breeding populations were screened visually under heavy natural levels of inoculum without infector rows or specific sowing arrangements, for their reactions to early leaf spot.

All populations were rated as susceptible to early leaf spot but four interspecific derivatives, CG St. 17 B 24/1, CG St. 17 B 24/3, CS 15, and CS 19 retained significantly more leaves than other entries. Selections were therefore made for high yield and superior pod characteristics under high disease pressure. From the 226 populations screened, we made 91 single-plant and 181 bulk selections. Most of the selections were Spanish types.

Rust- and late leaf spot-resistant populations were only evaluated for yield at Chitedze because of low disease pressure.

Twenty *Phoma arachidicola*-resistant breeding lines were obtained from Zimbabwe where the disease is serious. As *P. arachidicola* is not a serious problem at Chitedze, the entries were only subjected to heavy natural early leaf spot pressure. The lines were vigorous, and took 140 to 157 days to mature. They were also tall and some had lodged at harvest. However, foliage retention was good compared to other material and 5 single-plant selections and 15 bulk selections were made from 14 of the lines. The remaining 6 lines were rejected because of poor yield. The line P84/6/20 was outstanding, one single-plant selection had 99 pods.

Table 41. Yields (kg ha^{-1}) of Spanish bunch type cultivars, ICRISAT Southern African Cooperative Regional Yield Trial, 1983/84.

	Pod yield (kg ha^{-1})						
	Malawi		Mozambique	Zambia		Zimbabwe	
Pedigree	Chitedze	Lupembe	Sabie[1]	Msekera	Magoye	Gwebi	Mean
1CGMS 5	1660	1540	1180	2240	1710	3290	2096
ICGMS 6	1800	1140	1330	1630	1360	3290	1840
ICGMS 11	1380	1850	1310	2100	1920	3510	2150
ICGMS 12	1440	1660	1180	1880	1500	2960	1890
ICGMS 13	1350	1400	1410	1780	1710	3320	1910
ICGMS 14	1280	1800	1340	1690	1830	2860	1890
ICGMS 21	1560	1410	1170	1860	2110	2360	1860
ICGMS 23	1760	1190	1220	2010	1210	2820	1800
ICGMS 28	1550	1230	1280	1960	1350	3270	1870
ICGMS 31	1800	1420	1740	1670	1070	4110	2010
ICGMS 33	1730	1610	1180	1840	1860	3120	2030
Controls							
Malimba	1460	1540	-	-	-	-	-
Spancross	1380	1440	-	-	-	-	-
Starr	-	-	1050	-	-	-	-
Comet	-	-	-	1830	1830	-	-
Plover	-	-	-	-	-	2690	-
Valencia R2	-	-	-	-	-	4010	-
SE	±88	±113	-	±114	±223	±159	-
Trial mean (n=36)	-	1500	1360	-	1850	1560	2580
CV (%)	12	17	-	12	28	12	-

1. Not analyzed or included in overall mean.

Aspergillusflavus. Fourteen F_6 and F_7 populations, involving the resistant parents PI 337409 and PI 337394 F, were obtained from ICRISAT Center in 1982, and advanced by single-pod descent, without any selection, for sowing in 1983/84. Four single-plant and 12 bulk selections were made on yield attributes in 11 of the populations, and 3 populations were discarded.

Virus diseases: rosette. Forty-eight individual plants and bulks from the interspecific material not affected by rosette last season were progeny rowed in 1983/84. Thirty-eight selections proved to be susceptible and from the others, we selected five apparently disease-free and high-yielding individual plants, and five bulks. Fifty-two F_1 plants from crosses of resistant and susceptible parents were grown under protected conditions as rosette resistance is a recessive character. Two F_1s were rejected as selfs and the remainder were harvested and will be grown in the 1984/85 season.

Breeding for High Yield and Quality

Breeding material. We grew 47 F_1s with their parents in the field, assessed 550 F_2 to F_{11} populations, and discarded 270. From the remainder, we made 153 single-plant selections and 359 new bulks on visual characters. Seven Spanish, and one Virginia selection, with sufficient seed, were earmarked for inclusion in the 1984/85 yield trials.

Yield trials. We sowed seven replicated yield trials including an F_2 yield trial, an F_2 line x

Table 42. Pod yields (kg ha^{-1}) of Virginia bunch-type cultivars, ICRISAT Southern African Cooperative Regional Yield Trial, 1983/84.

	Pod yield (kg ha^{-1})						
	Malawi		Mozambique	Zambia		Zimbabwe	
Pedigree	Chitedze	Meru	Namialo[1]	Msekera	Golden Valley	Gwebi	Mean
ICGMS 35	1660	1690	560	2110	1370	2060	1780
ICGMS 38	1370	2250	880	1700	1160	2340	1770
ICGMS 39	1690	2040	520	2020	1230	1860	1770
ICGMS 40	1360	1590	740	950	1220	2500	1820
ICGMS 42	2650	2490	630	1800	1380	3560	2520
ICGMS 43	1790	2340	590	1260	1660	3270	2170
ICGMS 45	1620	3330	590	2250	840	3320	2270
ICGMS 47	1730	2350	410	2300	1040	2850	1480
Controls							
Mani Pintar	2380	2490	-	-	-	-	-
RRI/I	1720	2170	-	-	-	-	-
57-422	-	-	610	-	-	-	-
RMP12	-	-	570	-	-	-	-
Makulu Red	-	-	-	2260	1030	2790	-
Chalimbana	-	-	-	2300	530	-	-
Egret	-	-	-	-	-	3090	-
SE	±90	±197	-	±131	±132	±104	-
Trial mean (n=36)	1630	2200	-	1930	1140	2420	-
CV (%)	11	18	-	13	23	8	-

1. Not analyzed or included in overall mean.

tester trial, an F_4-F_6 early-generation yield trial, and an ICGS trial containing new entries. We also repeated three trials from the 1982/83 season.

Regional Trials

After initial evaluation and selection in 1982/83, and seed increase during the dry season under irrigation at Makanga, 34 Spanish populations and 14 Virginia populations were assigned 1CGMS numbers and selected for regional trials. For each trial there were two locations each in Malawi and Zambia, and one each in Mozambique and Zimbabwe. The trials in Mozambique were not analyzed due to highly variable emergence of both entries and controls. Results for some of the cultivars are shown in the Tables 41 and 42.

In the 1984/85 season, new trials have been located at two sites in Tanzania, Naliendele and Morogoro, and at Gaborone in Botswana. Only Spanish cultivars will be tested in Botswana as it is a low-rainfall area.

Seed Supply

Apart from seed supplied to breeders for regional trials, advanced breeding lines and segregating populations were supplied to Egypt, Gabon, Malawi, Mozambique, Swaziland, Zambia, and Zimbabwe.

Workshops, Conferences, and Seminars

Regional Workshop on Groundnut Research and Improvement in Southern Africa

This meeting took place in Lilongwe, Malawi, 26-29 March. There were 46 participants representing various institutions in six countries of the region: Botswana, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe. IDRC who fund the Regional Groundnut Improvement Program for Southern Africa were represented by staff from Ethiopia and Kenya. Among the Malawi delegates were three USAID scientists, and three representatives from Bunda College of Agriculture, University of Malawi, as well as those from the Ministry of Agriculture. Papers covering the ICRISAT regional and center programs were presented, and each country reported on various aspects of groundnut production including breeding, seed production, agronomy, and disease problems. Special papers were presented on breeding methodology, training, survey methodologies, and economic aspects of crop production. A plenary session recommended future research priorities. Proceedings are in press and will be available from Information Services, ICRISAT.

International Group Discussion Meeting on Groundnut Rust Disease

Participants from 10 countries met with ICRISAT scientists, 24-28 September, to discuss all aspects of groundnut rust, which has become a serious disease in many parts of the world during the last decade. Papers were presented on taxonomy, epidemiology, sources and mechanisms of resistance, and breeding procedures that utilize both cultivars and wild species. Other aspects discussed were plant quarantine, and the possible existence of races of the pathogen. The present status of rust in the Americas, Australia, Burkina Faso, India, Nigeria, the Peoples' Republic of China, southern Africa, and Thailand was discussed. Proceedings are in press and will be available from Information Services, ICRISAT.

Looking Ahead

Diseases. Research on early leaf spot will be intensified, both at ICRISAT Center and at the ICRISAT Regional Program for Southern Africa. In particular, wild species and their derivatives will be screened in Malawi, together with further collections of cultivated germplasm reported to be resistant to early leaf spot in other countries.

More emphasis will be placed on epidemiological studies of the foliar fungal diseases in cooperation with national and regional programs. Cooperative research with ICRISAT Farming Systems scientists on the effects of diseases in intercropping situations will be strengthened.

Research on pod rots and the aflatoxin problem will receive higher priority. In particular we will try to combine by breeding, dried-seed resistance to invasion by *A. flavus* and low aflatoxin production levels, as these characters have not so far been found to occur together in a single cultivar.

Insect pests. Development of multiple-pest resistance will remain a major objective, but greater emphasis will be placed on integrated control methods, particularly where resistances are not available. Epidemiological studies on rosette, and research on vector movements and overwintering, will receive greater attention in Malawi and in cooperation with Peanut CRSP in West Africa.

Limited studies on storage pests will continue and methods for termite control without the use of inseticide will hopefully be implemented in cooperation with the Tropical Development and Research Institute (TDRI) and AICORPO.

Drought, nutrient stress, and photoperiod. We have now standardized our drought-screening techniques and we will try to identify sources of resistance or tolerance to drought that could be used in breeding programs. Cooperative studies on the interactions of high temperatures and drought on pod invasion by soil fungi will be carried out by physiologists and pathologists.

Research will continue on *Rhizobium* inoculation, inoculum quality, and physiological factors influencing nitrogen fixation. The role of mycorrhizae and the interactions of mycorrhizae and rhizobia will be initiated. The possible effects of photoperiod on cultivar adaptation in different latitudes will continue to receive high priority.

Plant improvement. Breeding for resistance to stress factors will continue, as will adaptive breeding for particular traits. In conjunction with our biochemists we will put more emphasis on quality factors of confectionery groundnuts and the keeping quality of oil in cultivars bred for crushing.

New international nurseries will be initiated and more emphasis will be given to selecting early-maturing cultivars for rice-based cropping systems in Southeast Asia.

Wild Species. We will continue to screen wild species for useful traits and incorporate them into desirable agronomic backgrounds by conventional and unconventional techniques. More basic studies will be needed on new accessions and we will continue our efforts to exploit species from compatible sections of the genus. Attention still needs to be paid to the production of haploids, to systems that control chromosome pairing and recombination, and to developing aneuploids to facilitate gene transfer and genetic analyses.

Publications

Institute Publication

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 98 pp.

Journal Articles

Arunachalam, V., Pungle, G.D., Dutta, M., Nambiar, P.T.C., and Dart, P.J. 1984. Efficiency of nitrogenase activity and nodule mass in predicting the relative performance of genotypes assessed by a number of characters in groundnut *(Arachis hypogaea).* Experimental Agriculture 20:303-309.

Arunachalam, V., Bandyopadhyay, A., Nigam, S.N, and Gibbons, R.W. 1984. Heterosis in relation to genetic divergence and specific combining ability in groundnut *(Arachis hypogaea).* Euphytica 33:33-39.

Azam-Ali, S.N. 1984. Environmental and physiological control of transpiration by groundnut crops. Agricultural and Forest Meteorology 33:129-140.

Bharathan, N., Reddy, D.V.R., Rajeshwari, R., Murthy, V.K., Rao, V.R., and Lister, R.M. 1984. Screening peanut germplasm lines by enzyme-linked immunosorbent assay for seed transmission of peanut mottle virus. Plant Disease 68(9):757-758.

Demski, J.W., Reddy, D.V.R., and Sowell, G., Jr. 1984. Peanut stripe virus - a new seed-borne potyvirus from China infecting groundnut *(Arachis hypogaea).* Annals of Applied Biology 105:495-501.

Demski, J.W., Kuhn, C.W., Misari, S.M., Casper, R., Ansa, O., and Reddy, D.V.R. 1984. Etiological studies on groundnut rosette. Phytopathology 74:627. (Abstract.)

Dwivedi, S.L., Nigam, S.N., Pandey, S.K., and Gibbons, R.W. 1984. Note on the inheritance of albinism in groundnut *(Arachis hypogaea* L.). Euphytica 33(3):705-708.

Iizuka, N., Rajeshwari, R., Goto, T., Reddy, D.V.R., Muniyappa, V., and Ghanekar, A.M. 1984. Natural occurrence of a strain of cowpea mild mottle virus on groundnut *(Arachis hypogaea* L.) in India. Phytopathologische Zeitschrift 109:245-253.

Mehan, V.K., and McDonald, D. 1984. Research on the aflatoxin problem in groundnut at ICR1SAT. Plant and Soil 79:255-260.

Mehan, V.K., and McDonald D. 1984. Mycotoxin-producing fungi in groundnuts. Potential for mycotoxin contamination. Oleagineux 39(1):25-29.

Nambiar, P.T.C., Dart, P.J., Srinivas Rao, B., and Ravishankar, H.N. 1984. Response of groundnut *(Arachis hypogaea* L.) to *Rhizobium* inoculation. Oleagineux 39:149-155.

Nambiar, P.T.C., Srinivasa Rao, B., and Anjaiah, V. 1984. Studies on competition, persistance, and methods of application of a peanut *Rhizobium* strain, NC 92. Peanut Science 11(2):83-87.

Nigam, S.N., Dwivedi, S.L., Sigamani, T.S.N., and Gibbons, R.W. 1984. Character association among vegetative and reproductive traits in advanced generation of interspecific and intrasubspecific crosses in peanut. Peanut Science 11(2):95-98.

Reddy, D.V.R., Bharathan, N., Rajeshwari, R., and Demski, J.W. 1984. Detection of peanut mottle virus in peanut seed by enzyme-linked immunosorbent assay. Phytopathology 74:627. (Abstract.)

Reddy, D.V.R., Subrahmanyam, P., Sankara Reddy, G.H., Raja Reddy, C, and Siva Rao, D.V. 1984. A nematode disease of peanut caused by *Tylenchorhynchus brevilineatus.* Plant Disease 68(6):526-529.

Sastri, D.C. 1984. Incompatibility in Angiosperms. Significance in crop improvement. Advances in Applied Biology (Coaker, T.H., ed.) 10:71-111.

Singh, A.K., and Moss, J.P. 1984. Utilization of wild relatives in genetic improvement *of Arachis hypogaea* L. V. Genome analysis in section *Arachis* and its implications in gene transfer. Theoretical and Applied Genetics 68:355-364.

Singh, A.K., and Moss, J.P. 1984. Utilization of wild relatives in genetic improvement of *Arachis hypogaea* L, VI. Fertility in triploids: Cytological basis and breeding implications. Peanut Science 11:17-21.

Singh, A.K., Subrahmanyam, P., and Moss, J.P. 1984. The dominant nature of resistance to *Puccinia arachidis* in certain wild *Arachis* species. Oleagineux 39(11):535-537.

Subrahmanyam, P., Williams, J.H., and McDonald, D. 1984. The influence of foliar diseases and their control by selective fungicides on a range of groundnut *(Arachis hypogaea* L.) genotypes. Annals of Applied Biology 104:467-476.

Conference Papers

McDonald, D. 1984. ICRISAT's research on groundnut. Pages 14-17 *in* Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Nambiar, P.T.C. 1984. The use of ELISA (Enzyme-linked immunosorbent assay) for quality assessment of bacterial inoculants. Page 19 *in* Abstracts of the Working Group Meeting on Cereal Nitrogen Fixation, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Nigam, S.N. 1984. Groundnut in southern Africa: its status and requirement. Pages 143-153 *in* Proceedings of the Oilseeds Workshop, 3-8 Sept 1983, Cairo, Egypt (Riley, K.W.,ed.). Giza, Egypt: International Field Crops Research Institute, and Ottawa, Canada: International Development Research Centre.

Reddy, L.J., Nigam, S.N., Subrahmanyam, P., Dwivedi, S.L., Gibbons, R.W., and McDonald, D. 1984. Development of foliar diseases resistant groundnut lines at ICRISAT. APRES Proceedings 16(1):38.

Reddy, D.V.R., and Rajeshwari, R. 1984. Cowpea mild mottle. Page 51 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

Subrahmanyam, P., McDonald, D., and Hammons, R.O. 1984. Rust. Pages 7-9 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H.,and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

Miscellaneous

Demski, J.W., Reddy, D.V.R., and Bays, D.C. 1984. Peanut stripe. Pages 51-52 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

McDonald, D., and Mehan, V.K. 1984. Charcoal rot. Pages 27-28 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

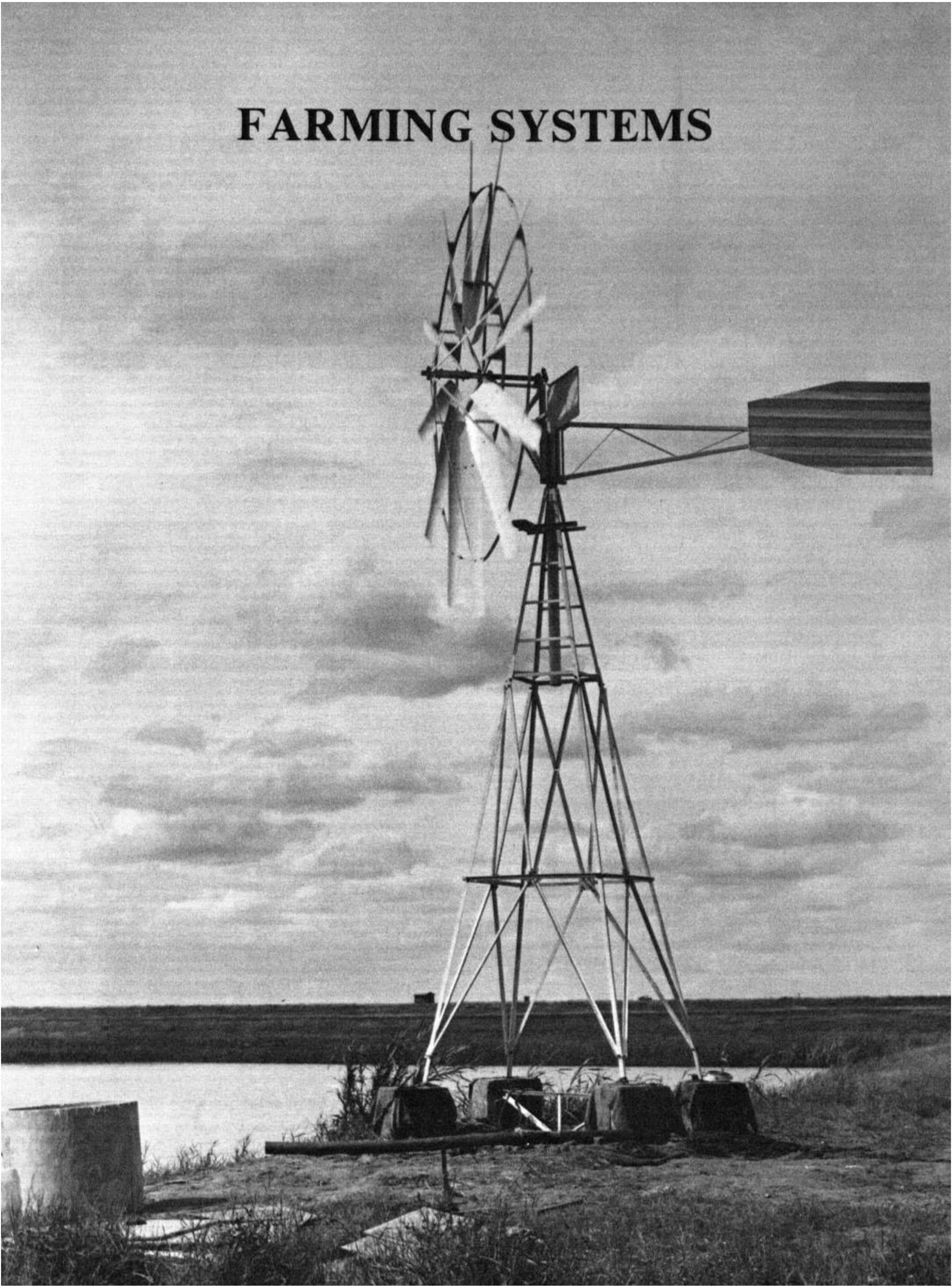
Nolt, B.L., and Reddy, D.V.R. 1984. Peanut clump. Pages 50-51 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

Reddy, D.V.R. 1984. Other viruses. Page 52 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

Reddy, D.V.R. 1984. Tomato spotted wilt virus. Pages 48-49 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

Reddy, D.V.R. 1984. Groundnut rosette. Pages 49-50 *in* Compendium of peanut diseases (Morris Porter, D., Smith, D.H., and Rodriguez-Kabana, R., eds.). St. Paul, Minnesota, USA: American Phytopathological Society.

FARMING SYSTEMS



Contents

Cover photo: Experimental windmill used to lift water from a storage structure, in studies on runoff-water recycling (left), ICRISAT Center, 1984.

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FARMING SYSTEMS

Farming Systems Research aims to develop improved management systems that make better use of the farmer's natural resources than his traditional systems. In earlier years, we focused our attention on deep Vertisols (black clay soils) in the more assured-rainfall areas of the Indian semi-arid tropics (SAT). This research led to the development of a double-cropping system that has the potential to increase productivity several-fold over farmers' traditional single-crop systems. Double-cropping also substantially reduces erosion. Currently, in conjunction with national programs, we are placing emphasis on the testing and adaptation of variants of this system in India, and we are also looking for situations across the SAT where we can recommend application of the main concepts.

Our component research is increasingly directed towards soils with less-assured moisture regimes. These include deep Vertisols in lower-rainfall areas, shallower black clay (Vertic) soils, and the lighter-textured Alfisols and Entisols.

In 1983, we formalized this change in our research direction in two ways. Firstly, we initiated a more intensive research program on soil and water conservation. Secondly, we identified the priority areas for farming systems research at the ICRISAT Sahelian Center (ISC) in Niger, where sandy soils and low rainfall create a much harsher environment than that at ICRISAT Center. Emphasis in West Africa at this stage is placed on interdisciplinary research including animals and agroforestry, two areas not previously studied by ICRISAT. Although our major long-term agroforestry research will be in Africa, the short-term program that we have started at ICRISAT Center will be particularly useful because of its evaluation of methodological approaches, especially for assessing the interactions between perennial tree species and annual crops.

In addition to these newer activities, we are maintaining ongoing disciplinary research with emphasis on improved cropping systems, characterization of moisture regimes, optimum use of water and fertilizers, and maintenance of soil fertility.

On-Station Component Research

Agroclimatological Studies

This year at ICRISAT Center the season started with rains that occurred in the 2nd week of June. Afterwards, water recharging of Vertisols and Alfisols continued, except for a short dry spell that occurred from the last week of June to early July. With later rains, the Alfisol profile was fully charged by the middle of July, and the Vertisol profile by early August. This was followed by two further dry spells resulting in nearly complete removal of available soil water in Alfisols in September and October. The crops suffered more severely in Alfisols than in Vertisols. After the second week of October, the available water in Alfisols and Vertisols gradually declined.

Pearl Millet Response to Sowing Geometry

We studied the growth of pearl millet under three sowing geometries on an Alfisol in the 1982 and 1983 rainy seasons. Two pearl millet genotypes, BJ 104 and ICH 226, were sown on 20 June in 1982, and 29 June in 1983. We imposed three levels of rectangularity of the inter- and intra-row spacings of a fixed population of 100000 plants ha^{-1}. These spacings were 37.5 x 26.6 cm (S_1), 75.0 x 13.3 cm(S_2), and 150.0 x 6.6 cm (S_3). We used a randomized block design with three replications, and applied N at 28 and P at 12 kg ha^{-1} at sowing, and an additional 28 kg N ha^{-1} (as urea) 22 days after emergence (DAE). We measured growth and yield components in both years, and light interception in 1982. Total rainfall during the crop-growth period was 376 mm in 1982 and 835 mm in 1983.

Leaf area index (LAI). ICH 226 had a higher LAI than BJ 104 throughout the rainy season in 1982 (Fig. 1). LAI increased rapidly from 21 to 42 DAE in all treatments. Maximum LAI was generally lower in the S_3 treatment. Contribution to LAI by tillers was unaffected by sowing geometry.

Light interception and light-use efficiency. The S_3 sowing geometry intercepted least light between about 30-60 DAE, and light interception by ICH 226 canopies tended to be higher than BJ 104 between about 45-60 DAE (Fig.2). We attribute both effects to the LAI (Fig. 1). The extinction coefficient (K) for both cultivars was similar, but K values were -0.63 for S_1, -0.57 for S_2, and -0.36 for S_3. The dry matter produced MJ^{-1} of photosynthetically active radiation (PAR) intercepted was calculated on a seasonal basis (Table 1): BJ 104 produced approximately 2.09, and ICH 226 produced 2.29 g MJ^{-1}.

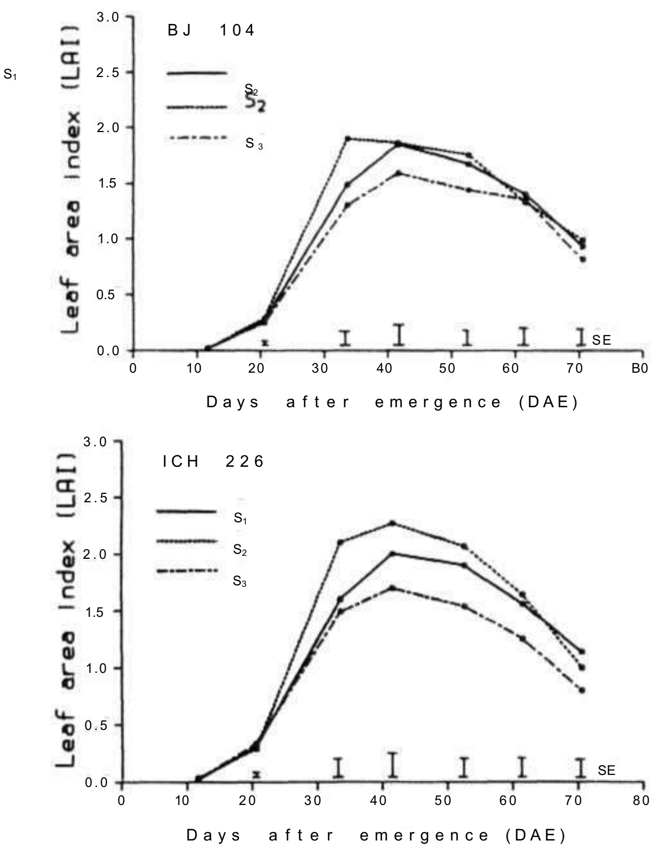


Figure 1. Leaf area indices of two pearl millet genotypes grown at three sowing geometries on an Alfisol, ICRISAT Center, rainy season 1982.

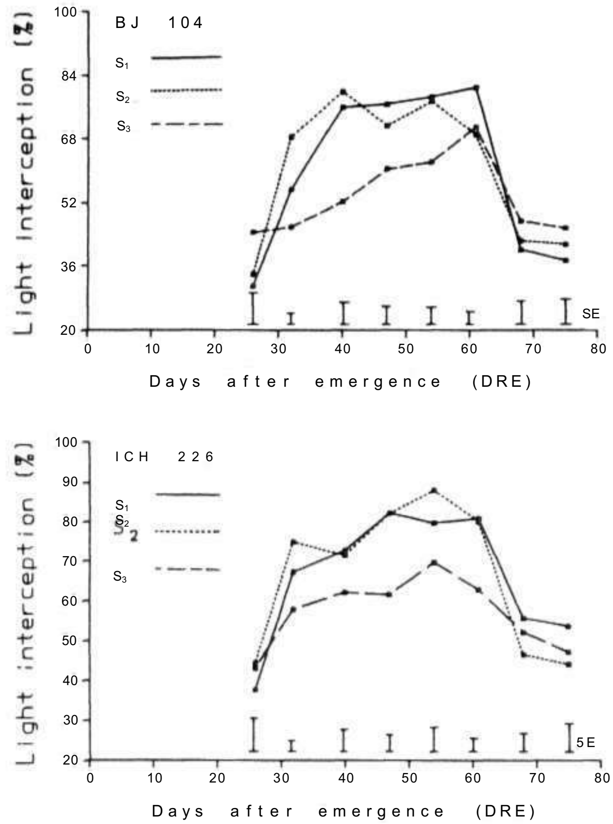


Figure 2. Interception (%) of photosynthetically active radiation by two pearl millet genotypes grown at three sowing geometries on an Alfisol, ICRISAT Center, rainy season 1982.

Yield. The most rectangular plant spacing consistently reduced grain and total dry-matter (TDM) yield (Table 2), but did not affect the partitioning of TDM into grain as shown by harvest index. In 1982, but not 1983, there was a significant interaction ($P < 0.01$) between the effect of genotype and sowing geometry on grain yield: BJ 104 yielded less than ICH 226 at the S_3 geometry, but not at the S_1 or S_2 geometries. ICH 226 had a greater 1000-grain mass than BJ 104. Grain yields averaged 2270 kg ha^{-1} in 1982 and 1820 kg ha^{-1} in 1983. We attribute the lower yield in 1983 to lower solar radiation and excessive rainfall during the crop-growth period.

Water use and water-use efficiency. Sowing geometry did not affect water use by pearl millet in 1982, but ICH 226 used more water than BJ 104 and its water-use efficiency (WUE) for total dry matter (TDM) was lower (Table 3). For both genotypes, S_3 caused a lower WUE for both grain and TDM yield than S_1 and S_2. In an interaction between genotype and sowing geometry, ICH 226 at the S_2 sowing geometry gave the highest WUE (191 kg ha^{-1} cm^{-1}); for BJ 104, the S1 sowing geometry gave the highest WUE (165 kg ha^{-1} cm^{-1}).

We conclude that conversion efficiency of intercepted radiation into TDM is conservative for the two genotypes and various sowing geometries. In contrast, sowing geometry significantly affected total light interception and extinction coefficient. Different geometries did not change the crop's water use, but did affect the WUE.

Pearl Millet Response to Water Deficit

We started an experiment on an Alfisol during

Table 1. Efficiency of conversion of photosynthetically-active radiation into total dry matter (TDM) by two pearl millet genotypes grown at three sowing geometries on an Alfisol, ICRISAT Center, rainy season 1982.

Cultivar	Sowing geometry[1]	Conversion efficiency (g MJ^{-1})	SE
BJ 104	S1	2.0	±0.13
	S2	1.9	±0.07
	S3	2.1	±0.16
ICH 226	S1	2.2	±0.10
	S2	2.1	±0.08
	S3	2.3	±0.17

1. Sowing geometries: S_1 = 37.5 x 26.6 cm; S_2 = 75.0 x 13.3 cm; S_3 = 150 x 6.6 cm.

Table 3. Water use (WU) and water-use efficiency (WUE) of two pearl millet genotypes grown at three sowing geometries, Alfisol, ICRISAT Center, rainy season 1982.

Cultivar	Sowing geometry[1]	Water use (cm)	Water-use efficiency (kg ha^{-1} cm^{-1}) Grain	Dry matter
BJ 104	S_1	36.4	69	165
	S2	36.2	64	154
	S3	36.5	52	136
ICH 226	S_1	38.3	61	165
	S2	37.7	65	191
	S3	37.8	56	155
SE		±0.6	±2	±5

1. See Table 1 footnote 1.

Table 2. Grain yield, TDM, harvest index, and 1000-grain mass of two pearl millet cultivars grown at three sowing geometries on an Alfisol, ICRISAT Center, rainy seasons 1982 and 1983.

Cultivar	Sowing geometry[1]	Grain yield (kg ha^{-1}) 1982	1983	TDM (kg ha^{-1}) 1982	1983	Harvest index (%) 1982	1983	1000-grain mass (g) 1982	1983
BJ 104	S1	2490	1950	5990	4900	41.6	39.8	6.4	6.0
	S2	2320	1890	5570	4860	41.7	39.2	6.1	5.9
	S3	1900	1730	4970	4220	38.2	40.9	6.2	6.7
ICH 226	S1	2350	1820	6310	4860	37.2	37.5	6.9	7.1
	S2	2440	1850	7220	4870	33.8	38.2	7.0	6.9
	S3	2120	1660	5870	4260	36.0	38.9	6.3	6.6
SE		±69	±101	±164	±363	±1.20	±1.98	±0.30	±0.24

1. Sowing geometries: S_1 = 37.5 x 26.6 cm; S_2 = 75.0 x 13.3 cm; S_3 = 150 x 6.6 cm.

summer 1983 to study the effect on pearl millet of drought stress imposed at different phenological stages. The experiment was arranged in a split-plot design with 3 replications. Five stress treatments formed the main plots and the two cultivars (BJ 104 and 1CH 412) the subplots. The treatments were:

- M_0: adequate moisture supply throughout the growing season;
- M_1: drought stress during growth stage 1 (GS_1), i.e., from emergence to panicle initiation;
- M_2: stress during GS_2, i.e., from panicle initiation to anthesis;
- M_3: stress during GS_3, i.e., from anthesis to physiological maturity; and
- M_4: stress from later part of GS_2 to end of GS_3.

Seed was sown on 27 January, and plant growth and development, dry-matter partitioning, water use, and WUE were measured.

Total dry matter. Table 4 shows the contribution to TDM by main culms and tillers of the two cultivars. Main culms contributed more than tillers to TDM of ICH 412 in most treatments, and tillers contributed more in BJ 104 in all treatments. ICH 412 produced more *(P*<0.05) TDM (main culm + tillers) than BJ 104 in 2 of the 5 treatments. Drought during GS_2 delayed flowering in ICH 412, thus the crop experienced a longer period of stress in M_2. TDM of ICH 412 for this treatment (M_2) was 48% lower than that for the M, treatment; however, the reduction in TDM for BJ 104 was only 14%. TDM yields were reduced most by treatment M_3 for BJ 104, and by M_4 for ICH 412.

Grain yield. The grain yield (main culms + tillers) of BJ 104 was greater than that of ICH 412 (Table 5) for all except the M_3 treatment. Tillers provided most of the grain yield of BJ 104, again except the M_3 treatment. Main culms usually provided most of the grain for ICH 412. In BJ 104, tillers contributed most (75%) to grain yield in M_2 resulting in a total grain yield of 2750 kg ha^{-1}; M_0 and M_1 gave similar yields. Drought stress during GS_2 reduced grain yield of the main culm by over 40% in both cultivars, but increased that from the tillers by 27%; in BJ 104 and 125% in ICH 412. Drought stress during the grain filling period (M_3) reduced total grain yield by 73% in BJ 104 and 68% in ICH 412.

Water use and water-use efficiency. ICH 412 used more water than BJ 104 in the M_0 and M_1 treatments (Table 6). BJ 104 used similar amounts of water in M_0, M_1, and M_4. Both cultivars used least water in M_2. Water use by

Table 4. Effect of five drought-stress treatments on TDM (kg ha^{-1}) of two pearl millet cultivars, Alfisol, ICRISAT Center, summer 1983.

Drought-stress treatment	TDM (kg ha^{-1})					
	Main culms		Tillers		Main culms + Tillers	
	BJ 104	ICH 412	BJ 104	ICH 412	BJ 104	ICH 412
M_0	2890	5970	4530	2840	7430	8810
M_1	2900	5870	5010	4090	7910	9960
M_2	1950	2000	4850	3150	6800	5150
M_3	1670	3960	2150	2150	3830	6110
M_4	2110	1670	4200	1260	6310	2930
SED[1]	±297		±436		±560	
SED[2]	±344		±478		±666	

1. Standard error of the difference between two treatment means for the same cultivar.
2. Standard error of the difference between two cultivar means at the same level of moisture.

Table 5. Effect of five drought-stress treatments on grain yield (kg ha^{-1}) of two pearl millet cultivars, Alfisol, ICRISAT Center, summer 1983.

	Grain yield (kg ha^{-1})					
	Main culms		Tillers		Main culms + Tillers	
Treatment	BJ 104	ICH412	BJ 104	ICH 412	BJ 104	ICH412
M_0	1230	1410	1610	400	2840	1810
M_1	1030	1470	1810	750	2840	2210
M_2	690	840	2050	900	2750	1740
M_3	410	480	350	110	770	590
M_4	1030	540	1530	0	2560	540
SED[1]	±132		±149		±223	
SED[2]	±151		±172		±254	

1. Standard error of the difference between two treatment means for the same cultivar.
2. Standard error of the difference between two cultivar means at the same level of moisture.

both cultivars under M_3 and M_4 exceeded the amount of irrigation water applied.

BJ 104 was more efficient in its use of water for grain yield than ICH 412, for most of the treatments, as shown by the higher WUE for grain yield. For both cultivars, M_2 gave the greatest WUE for grain yield. M_3 of BJ 104, and M_3 and M_4 of ICH 412, caused the lowest WUE for grain yield. For BJ 104, the treatments caused similar effects on the TDM and grain yield WUEs. However, for ICH 412, M_3 gave a WUE for TDM that was similar to the highest WUEs for TDM (similar to M_4). These results show that grain filling (GS_3) is the growth stage most sensitive to drought stress; water applied at this stage is most efficiently used. Thus, under limited-water conditions, irrigation water could be withheld at GS_1 and GS_2, for application later in GS_3. BJ 104 uses water more efficiently than ICH 412, for both grain and TDM yield, due to the greater contribution of its tillers to the grain yield under both stressed and nonstressed conditions.

Table 6. Effect of five drought-stress treatments on WD **and** WUE for **grain yield and TDM production by two pearl millet cultivars, Alfisol, ICRISAT Center, summer 1983.**

			WUE (kg ha^{-1} cm^{-1})			
Drought-stress treatments	WU (cm)		Grain yield (kg ha^{-1})		TDM (kg ha^{-1})	
	BJ 104	ICH 412	BJ 104	ICH 412	BJ 104	ICH 412
M_0	37.7	47.1	75	38	197	187
M_1	34.4	43.7	83	**51**	232	228
M_2	22.8	**24.1**	121	74	**299**	213
M_3	30.9	32.8	25	18	125	187
M_4	35.8	36.2	71	15	176	81
SED[1]	±1.7		±7		±21	
SED[2]	±1.4		±7		±23	

1. Standard error of the difference between two treatment means for the same cultivar.
2. Standard error of the difference between two cultivar means at the same level of moisture.

Crop-Weather Modeling

Sorghum

Application of SORGF. In previous years we used the revised SORGF model to provide preliminary answers to questions on screening environments for sorghum production, selecting appropriate sowing dates, and predicting when and how much irrigation water to apply for optimum grain yield (ICRISAT Annual Report 1983, p. 239). This year the revised model was used to obtain the cumulative probability of fertilizer N requirement for sorghum production at ICRISAT Center. To achieve this, grain yields of sorghum for the rainy season were first simulated for a medium-deep Vertisol (150 mm available water-holding capacity) using weather data for 1901-1970 (Fig. 3). Under good management (timely field operations, adequate fertilizer, and plant protection), we predict that sorghum will yield at least 3000 kg ha^{-1} of grain in 70% of the years. We calculate fertilizer requirement on the assumption that 20 kg N is required to produce 1000 kg ha^{-1} of sorghum. The crop absorbs 55% of the fertilizer, and the N-uptake from the plot without fertilizer is 30 kg ha^{-1}, i.e., without fertilizer, a crop would yield 1500 kg ha^{-1}. For the ICRISAT Center environment, we predict in 50% of the years, a yield of 3800 kg ha^{-1} for which the fertilizer N requirement would be 80 kg ha^{-1}; and in 75% of the years we predict a yield of 3200 kg ha^{-1} for which fertilizer N requirement would be 60 kg ha^{-1}.

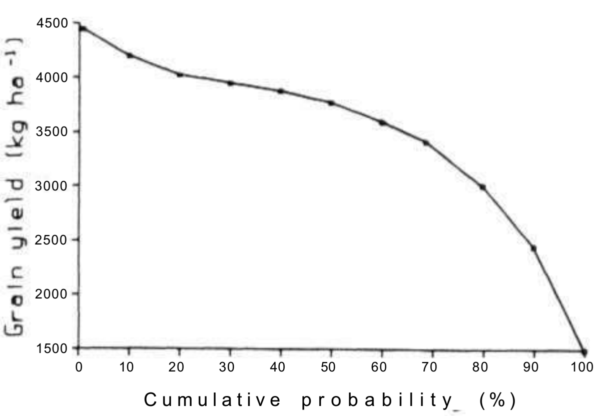


Figure 3. Cumulative probability of simulated sorghum grain yield (kg ha^{-1}) based on climatic data 1901-70.

Table 7. Simulated mean grain yield (kg ha^{-1}) and fertilizer N requirement (kg ha^{-1}) with drought stress alleviated by irrigation at different growth stages for sorghum sown 15 September on medium-deep Vertisols, Bijapur, Karnataka, postrainy seasons 1965-81.

Irrigation[1]			Mean grain yield	Mean fertilizer N requirement
Sowing	Panicle initiation	Anthesis	(kg ha^{-1})	(kg ha^{-1})
-	-	-	2100	23
+	-	-	2200	25
+	+	-	2400	33
+	-	+	3200	62
+	+	+	3400	70

1. - = Irrigation not applied; + = Irrigation applied.

The revised SORGF model was also used to simulate the response of sorghum grain yield to irrigation applied at different growth stages in Bijapur, Karnataka (Table 7), where mean annual rainfall is 646 mm. Under rainfed conditions the simulated mean sorghum grain yield for 16 years (1965-81) was 2100 kg ha^{-1} and the simulated mean fertilizer N requirement was 23 kg ha"[1]. The N-uptake without added fertilizer N was assumed to be 30 kg ha^{-1}. When a 50-mm irrigation was applied at sowing, and again at anthesis, the simulated mean grain yield was 3200 kg ha^{-1}, and fertilizer N requirement was 62 kg ha^{-1}.

The revised SORGF model was tested using independent data supplied by ICRISAT Sorghum Improvement Program on sorghum hybrid CSH 6 grain yields for the rainy seasons 1978-83 (Table 8). These crops were grown with a 75-cm row spacing on a medium-deep Vertisol (150 mm available water-holding capacity) at ICRISAT Center. We simulated grain yields using actual weather data for the whole growing season, and from sowing to anthesis; for the latter we assumed that normal weather prevailed during the period from anthesis to physiological

Table 8. Actual and simulated grain yield (kg ha^{-1}) of sorghum CSH 6 for ICRISAT Center using actual weather data for the growing season and from sowing to anthesis).

Sowing date	Actual grain yield (kg ha^{-1})	Simulated grain yield (kg ha^{-1})	
		Anthesis	Maturity
1 Jul 78	6230	5450	5650
23 Jun 79	5590	5710	5940
11 Jun 80	4880	5190	4950
24 Jun 81	5200	5550	5600
18 Jun 82	6630	5830	5600
28 Jun 83	5280	5470	4900
10 Jun 84	5000	5590	5240

Table 9. Actual and simulated grain yield (kg ha^{-1}) of pearl millet BJ 104 for ICRISAT Center using actual weather data for the growing season and from sowing to anthesis.

Sowing date	Actual grain yield (kg ha^{-1})	Simulated grain yield (kg ha^{-1})	
		Anthesis	Maturity
27 Jun 78	2430	2680	2610
5 Jul 80	1710	2560	2510
23 Jun 81	2880	2610	2620
28 Jun 82	2560	2750	2710
27 Jun 83	2240	2400	2280

maturity. Simulated sorghum grain yields were within 10% of the actual grain yields except in 1982. Thus the model could be used to forecast yields much ahead of harvest.

Pearl Millet

The framework for a pearl millet simulation model was described earlier (ICRISAT Annual Report 1983, p. 242). For BJ 104, the growing-degree-day requirements (base temperature 7°C) for the three growth stages GS_1, GS_2, and GS_3 were 350, 470, and 570. We used a simple approach involving the concept of ground cover coefficient (GC) similar to that used in groundnut. The GC was assumed to increase linearly from 0 to 1.0 from emergence to anthesis; it remained 1.0 for about a week after anthesis; and then it declined linearly to 0.5 at physiological maturity. For each MJ of radiation intercepted, 1.3 g of dry matter was produced. A harvest index of 0.25 was used to convert TDM to grain yield. This model was tested with an independent data set supplied by ICRISAT Pearl Millet Improvement Program. The crops were grown at 75-cm row spacing on an Alfisol (85 mm available water-holding capacity) at ICRISAT Center. Simulated grain yields (Table 9) were generally within 9% of the actual yields except in 1980, when simulated yield was 47% higher than actual yield.

Nutrients

Phosphorus

During earlier investigations into the behavior of phosphorus in Vertisols at ICRISAT Center (ICRISAT Annual Report 1983, pp. 254-255) we found that sorghum grown on deep Vertisols responded little, if at all, to applications of fertilizer P when the soil-available P content was very low (<2-3 ppm Olsen P). Our subsequent investigations have involved characterization studies to compare the forms of phosphorus existing in the benchmark Vertisols and Alfisols at the Center, and subsequent field and greenhouse experiments where we attempted to establish relationships between different estimates of available P in the soil, and the response of sorghum to applications of fertilizer P.

Characterization of Soil Phosphorus

We carefully chose four sampling sites on the benchmark Alfisol (Udic Rhodustalf) and four on the benchmark Vertisol (Typic Pellustert) at ICRISAT Center to provide soil samples with a range of available P levels for each soil order. We then examined the soils using the modified Chang and Jackson fractionation method to determine the forms in which phosphorus was held in the soil.

Our results (Fig. 4) show that amounts of P in the different fractions were quite consistent within each soil order, but there were large differences between the two orders. Calcium-P was the dominant form in the Vertisols; although iron-P dominated in the Alfisols, the levels present were about the same as those in the Vertisols. Aluminium-P was low in both soils.

Vertisols in India are considered to possess a high P-fixation capacity. In preliminary measurements on surface samples (0-15 cm) from the two soil orders, however, Vertisols fixed only slightly more phosphorus than Alfisols. When 200 mg P kg^{-1} was added to the soils, Vertisols sorbed 91% (on average) and Alfisols 86%; for smaller amounts added, e.g. 50 mg P kg^{-1}, the percentages sorbed were 96.6 by Vertisols and 97.1 by Alfisols. These results, obtained on the surface soils, were complemented by others showing that fixation in the type profiles of the two benchmark soils changed only a little with depth, apart from a high value in the B horizon of the Alfisol. The two soils hardly differed in their fixation capacities (Table 10).

Further research is warranted on the behavior of phosphorus in Vertisols because, in addition to a much lower P-fixation capacity than expected, assessments of plant responses indicate that Vertisols supply P to crops much more readily than has previously been recognized.

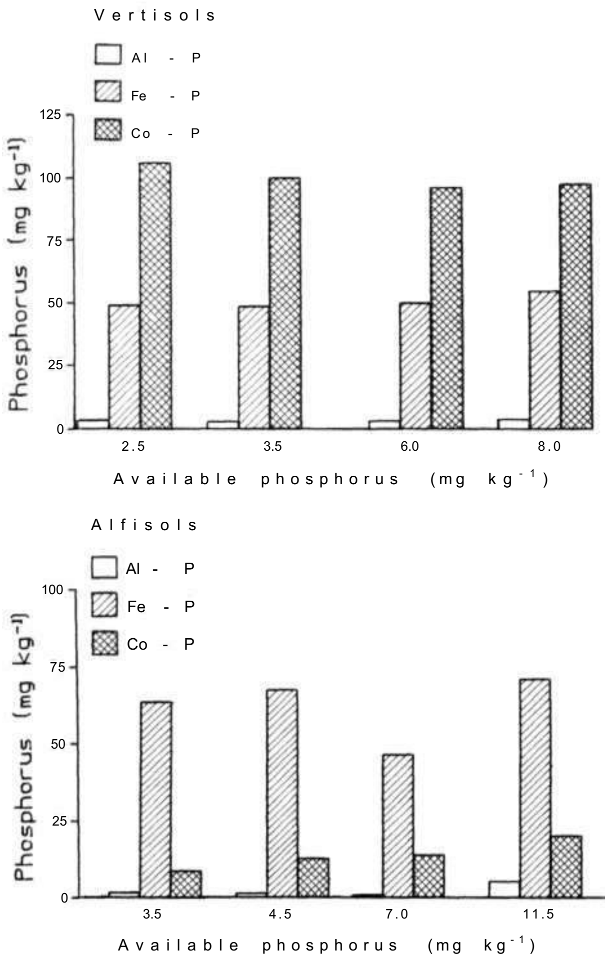


Figure 4. Phosphorus associated with Al, Fe, and Ca, as estimated by the Chang and Jackson procedure, in Vertisols and Alfisols, ICRISAT Center.

Responses to P Applied to Vertisols

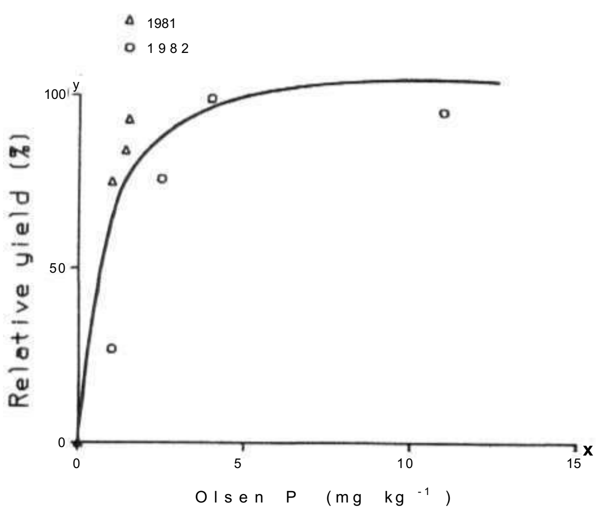
In 1983, we pursued the earlier indications that sorghum grown on Vertisols responded to fertilizer P applications only when the available P content of the soil was much lower than the limit used for other crops and soils in India. Available P was determined by the Olsen's standard method (extraction with 0.5 molar $NaHCO_3$). Rainy-season sorghum (CSH 6) was grown on the four Vertisol sites used to provide samples for soil P characterizations (Fig. 4). The sites received fertilizer treatments in a full factorial of five rates of P application (0, 5, 10, 20, and 40 kg ha^{-1}) and three rates of N application (40, 80, and 120 kg ha^{-1}). There was no interaction between N and P in the effects of nutrient additions on grain yield, and the main effects of P were therefore used to calculate the relative yield (Y_{P0}/Y_{Pmax}) for each site; the plot of these against available P (Olsen) in the soils shows that we only obtained appreciable responses on sites where the soil-available P content was less than about 2.5 ppm (Fig. 5). This is about one-half of the level generally used for other soils in India; a level of 5 ppm is considered to be low, and 10 ppm adequate. The lack of a significant N x P interaction was consistent with the results we obtained in a very detailed experiment in 1981.

This experiment involved 5 rates of P and 6 rates of N, arranged in a split-plot design with N treatments in the main plots and P treatments in

Table 10. Comparison of selected soil properties and amount of P fixed in the profiles of benchmark Vertisol and Alfisol, ICRISAT Center.

Soil							P added to reach 0.2 ppm
Horizon	Depth (cm)	Clay (%)	Organic C (%)	pH (1:2 H_2O)	$CaCO_3$ (%)	Total P (mg kg-')	equl. conc. (mg kg^{-1})[1]
Alfisol (Udic Rhodustalf)							
AP	0-10	19	0.62	6.3	2.4	140	35
B1	10-20	30	0.66	6.4	2.8	120	34
B21t	20-50	41	0.63	6.7	2.9	110	36
B22t	50-105	4!	0.49	6.6	2.8	90	93
BC	105-145	24	0.20	7.4	3.7	90	39
C	145-160	16	0.10	8.0	6.5	140	20
Vertisol (Typic Pellustert)							
AP	0-15	51	0.66	8.3	10.0	220	30
AII	15-40	54	0.33	8.5	9.3	150	33
A12	40-90	56	0.37	8.9	12.6	160	33
A13	90-150	59	0.29	8.9	15.2	190	38
AC	150-180	65	0.18	8.7	10.2	200	28

1. Amount of P added to result in a concentration of 0.2 mg P L^{-1} in supernatant solution, on equilibrating soil for 6 days at 25°C.



$$y = 96.7(1-e^{-1.02}x)$$

Figure 5. Relationship between relative grain yield (Y_{PO} /Y_{Pmax}) of rainy-season sorghum CSH 6 and available P (Olsen) in 0-15 cm depth of Vertisols; field experiments, ICRISAT Center, 1981 and 1982.

the sub plots. The response to P was small, about 6% on average (Table 11). We had expected that this site, with its low N and P status (1.5 ppm Olsen P) in the 0-15 cm soil depth, would be most likely to show N x P interactions in crop yield; the high maximum crop productivity (>6300 kg ha^{-1}) demonstrates the high crop demand for P from the soil. The lack of an interaction in this experiment, and in the other experiments providing data for Figure 5 indicate that these interactions are unlikely in our Vertisols.

In a greenhouse pot experiment, we investigated the feasibility of obtaining more precise comparisons between Vertisols and Alfisols. Bulk samples were collected from the 0-15 and 15-30 cm depths from each of the sites used for the soil characterizations in Figure 4. To the soil from each site, we added 6 rates of P (0, 0.5, 1, 2, 4, and 8 P m^{-2}, equivalent to 0, 5, 10, 20,40, and 80 kg P ha^{-1} on an area basis). We also applied other known essential nutrients as a basal dressing to the 0-15 cm soil depth including N at the rate of 12 g m^{-2}.

Table 11. Effects of N and P application on grain yield (kg ha^{-1}) of sorghum CSH 6, deep Vertisol, ICRISAT Center, rainy season 1982.

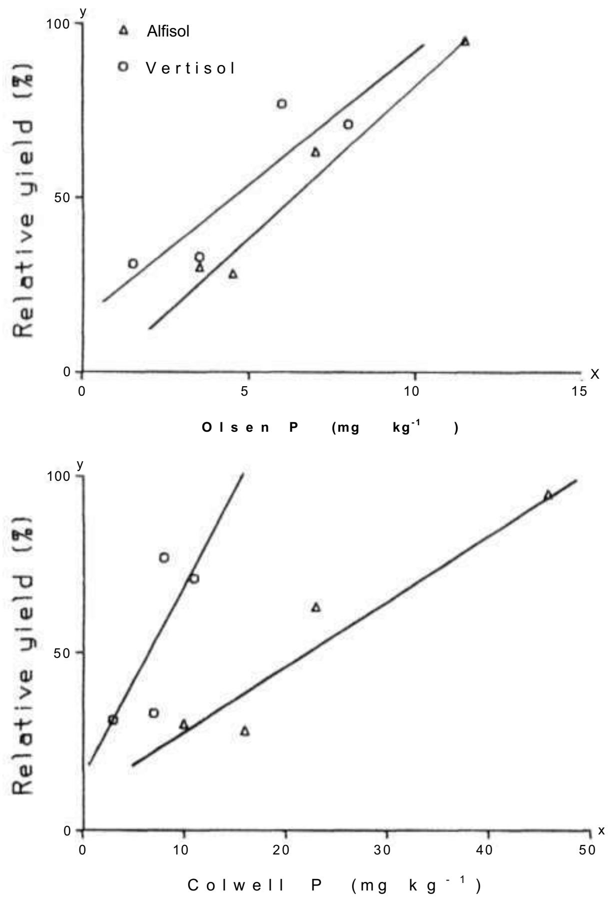
N rate	P rate (kg ha^{-1})						
(kg ha^{-1})	0	5	10	20	40	Mean	SE
0	1870	2050	2040	2130	2340	2090	
40	3950	3500	3560	3600	3610	3640	
80	4890	4580	5040	4620	4880	4800	±276
120	4560	5250	5440	5150	5350	5150	
160	5460	5420	5740	6020	5500	5630	
200	5580	5660	5850	6070	6350	5900	
SE			±401				
Mean	4390	4410	4610	4600	4670	4530	
SE			±126				

The results (Fig. 6a) did not indicate a clear difference between Vertisols and Alfisols in the relationships between the response of sorghum to added P, and the level of available P in the soil as assessed by the Olsen soil test. Significant differences resulted when the Olsen test was replaced by the Colwell test (Fig. 6b), which is very similar, but involves a more exhaustive extraction of soil P. The results, however, were contrary to those expected—the Colwell test had been expected to extract much more P from the Vertisol than from the Alfisol.

While these preliminary studies did not produce consistent results, they have very clearly highlighted the differences in P behavior in Vertisols and Alfisols. This has considerable relevance to fertilizer strategies for the improved double-cropping system for deep Vertisols.

Efficiency of Nitrogenous Fertilizers

Our collaborative project with the International Fertilizer Development Center (IFDC) commenced in 1980 to study the fate and efficiency of fertilizer N, initially focused on obtaining baseline information on deep Vertisols and Alfisols. In 1983 the research focus was shifted to shallow soils in which applied fertilizer N is more vulnerable to losses by leaching of variable rainfall. We compared different N sources on a shallow black soil (Vertic Inceptisol) using sole sorghum as the test crop. Earlier studies (ICRISAT Annual Reports 1981, pp. 231-233; 82, pp. 247-250; 83, pp. 257-259) examined the effects of method of application on the fate and efficiency of fertilizer N in different cropping systems, mainly on deep Vertisols. We continued studies on sorghum-safflower double cropping on a deep Vertisol, millet/groundnut intercrops on an Alfisol, and



a. $y = 16.8 + 7.6x$ $r = 0.89$ rse = 13.6
$y = -3,9 + 8.7x$ $r = 0.98$ rse = 7.1

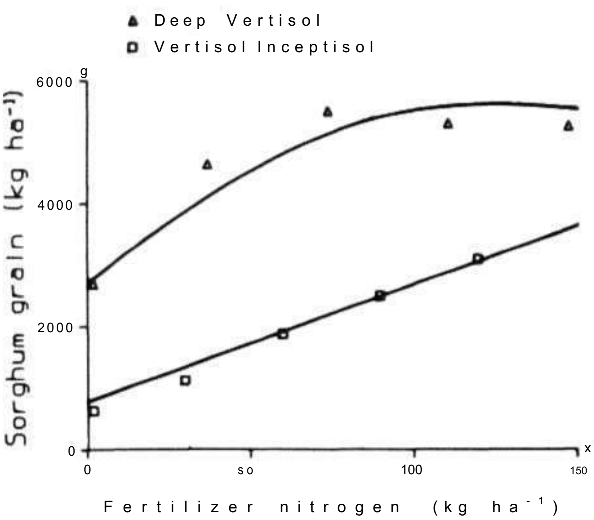
b. $y = 12.3 + 5.6x$ $r = 0.76$ rse = 19.4
$y = 8.4 + 1.9x$ $r = 0.96$ rse = 11.0

Figure 6. Relationships between relative grain yield of postrainy-season sorghum CSH 8 grown on Alfisols and Vertisols in a pot experiment, and available P assessed by the Olsen (a) and Colwell (b) methods in the 0-15 cm soil depth, ICRISAT Center, 1984.

we also compared different methods of fertilizer applications on shallow black (Vertic) soils.

Rainy-Season Sorghum on Vertic Soils

On these shallow soils, we studied the response of sorghum CSH 6 to urea applied at different rates (0-120 kg ha^{-1}) by the band-split technique, and the effectiveness of different N sources: urea, diammonium phosphate, potassium nitrate, nitrophosphate (20-20-0), and urea super granules (USG). The soil was a Vertic Inceptisol, average depth 25 cm. The rainfall in 1983 was well above normal, 913 mm between sowing and harvest, evenly distributed throughout the season. Sorghum responded linearly to applied N up to 120 kg N ha^{-1}, and the slope of the response curve was 20 kg of sorghum grain kg^{-1} N applied (Fig, 7). This result was markedly different from the earlier result (1981) on a deep Vertisol and with similar rainfall, 880 mm. On the deep Vertisol the response of sorghum CSH 6 to applied N was quadratic; the response was



1. $y = 2560+48.9x-0.20x^2$ $R = 0.85$ rse = 495

2. $y = 600+20.8x$ $r = 0.99$ rse=90

Figure 7. Relationship between grain yield (kg ha^{-1}) of sorghum CSH 6 and fertilizer N applied on deep (1981) (1) and shallow (1983) (2) Vertic soils, ICRISAT Center, rainy seasons 1981 and 1983.

Table 12. Effect of different types of fertilizer N on yield (kg ha^{-1}) of sorghum CSH 6, deep Vertisol (1982), and Vertic Inceptisol (1983), ICRISAT Center, rainy seasons 1982 and 1983.

	Grain yield (kg ha^{-1})	
Fertilizer N	Vertisol	Vertic Inceptisol
Nil	2870	670
Urea	5250	1910
Potassium nitrate	5390	1780
Nitrophosphate	5490	1860
Urea Super Granule	5530	2470
SE	±180	±122
CV (%)	7	14

almost linear up to 74 kg N ha^{-1}, with a slope of 34 kg grain kg^{-1} applied N (Fig. 7).

The inputs of fertilizer N were less efficient in increasing crop yields on the shallow black soil than on the deep Vertisol. Thus, for most efficient use of fertilizer resources, deep Vertisols should receive a higher priority in fertilizer allocation. Nevertheless, short-term strategies for subsistence farmers should not ignore the possibility of using fertilizer N on N-responsive crops on shallow droughty soils, because the 20 kg grain kg*[1] N obtained on the Vertic Inceptisol in 1983 was quite a satisfactory economic response.

Among the four nitrogenous fertilizers tested—urea, USG, potassium nitrate, and nitrophosphate (20-20-0)—USG was significantly more effective in increasing sorghum yields on the Vertic Inceptisol than the other sources of N (Table 12). In the deep Vertisol in 1982, these four sources of N were found to be equally effective. On selected treatments of these experiments, we used ^{15}N-labelled fertilizers to determine the fate of applied N.

Nitrogen Fertilizer Application to Millet Intercropped with Groundnut on a Shallow Alfisol

In 1983, we applied four levels of N (0, 40, 80, and 160 kg N ha^{-1}) to pearl millet cultivar BJ 104 intercropped with groundnut Robut 33-1 in 1:3 and 2:6 crop-row arrangements. Millet responded significantly to applied N (Fig. 8). Sole millet responded the most. The lower response of millet when intercropped was the main cause of the reduced advantage of intercropping with inputs of fertilizer N (Table 13). In a separate experiment on sole millet, USG application resulted in greater ($P<0.05$) yield than urea (Table 14); a similar result was obtained with sorghum on shallow black soils. The reasons for the superiority of USG are being investigated.

Table 13. Effect of N application (kg ha^{-1}) on Land Equivalent Ratio (LER) of two crop-row arrangements for a millet BJ 104/groundnut Robut 33-1 intercrop, Alfisol, ICRISAT Center, rainy season 1983.

N applied (kg ha^{-1})	LER Row arrangement[1] 1:3	2:6
0	1.35	1.36
40	1.14	0.98
80	1.01	1.01
160	0.92	0.99
SE	±0.060	
CV (%)	13.0	

1. Crop-row arrangement of 1:3 and 2:6 rows of millet: groundnut; all inter-row distances 30 cm.

Sorghum-Safflower Double-Cropping System on a Deep Vertisol

In the 1983/84 season, we continued our study on the efficiency of fertilizer N applied to the sorghum-safflower double-cropping system involving sequential cropping in the rainy and postrainy seasons. The results were in agreement with the findings from 1982/83 in that the effect of fertilizer N on the postrainy-season crop (grown with stored soil water) was significant, and the residual effect of fertilizer N applied to the rainy-season crop (sorghum) on the subsequent crop (safflower) was small. However, this year's result contradicts last year's finding that rainy-season bare fallowing was not beneficial to the postrainy-season crop (Table 15). From this 2-year study, we conclude that in a double-cropping system involving nonlegume crops such as sorghum-safflower, fertilizer N should be independently applied to both crops, and that the beneficial effect of bare fallowing land during the rainy season on a postrainy-season crop may vary between seasons. We suspect that the

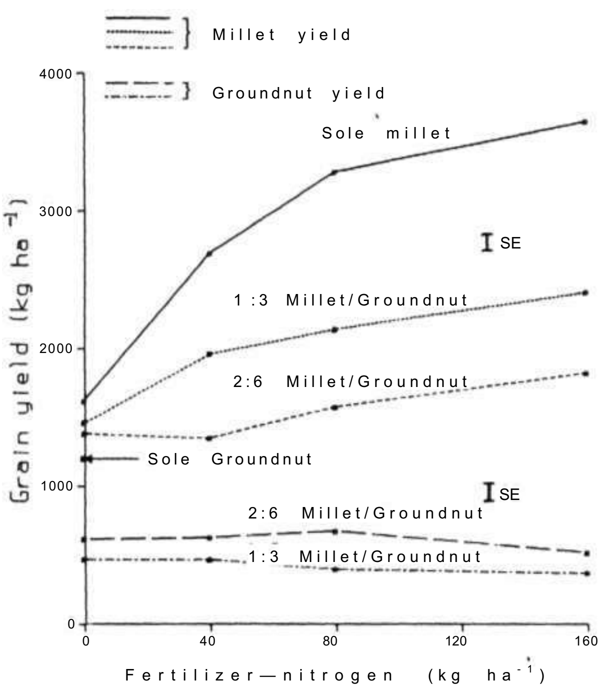


Figure 8. Effect of different crop-row arrangements and fertilizer N application rate on grain and pod yields (kg ha^{-1}) of intercropped millet and groundnut on an Alfisol, ICRISAT Center, rainy season 1983.

Table 14. Effect of different types of fertilizer N on yield (kg ha^{-1}) of sole millet BJ 104, Alfisol, ICRISAT Center, rainy season 1983.

Fertilizer N	Grain yield (kg ha^{-1})
Nil	1620
Urea	2700
Urea super granule	2930
SE	±87
CV (%)	9

Table 15. Effect of fertilizer N on grain yields (kg ha^{-1}) in sorghum-safflower double cropping, deep Vertisol, ICRISAT Center, 1982/83 and 1983/84.

Cropping system				Grain yield (kg ha^{-1})			
Rainy season		Postrainy season		Rainy season		Postrainy season	
Crop	N (kg ha^{-1})	Crop	N (kg ha^{-1})	1982[1]	1983[2]	1982/83	1983/84
Sorghum	0	Fallow	0	3550	1900	-	-
Sorghum	60	Fallow	0	4470	3520	-	-
Fallow	0	Safflower	0	-	-	1400	530
Fallow	0	Safflower	60	-	-	1960	1460
Sorghum	0	Safflower	0	3720	1100	630	690
Sorghum	60	Safflower	0	4890	3050	720	670
Sorghum	30	Safflower	30	4710	2270	1000	1170
Sorghum	60	Safflower	30	5180	3080	1050	1060
Sorghum	90	Safflower	0	5290	3920	860	840
Fallow	0	Sorghum	0	-	-	1410	1340
Fallow	0	Sorghum	60	-	-	2830	2910
SE				±175	±149	±90	±108
CV (%)				8	11	16	17

1. 1982 rainfall 500 mm.
2. 1983 rainfall 910 mm.

amount of rainfall during the fallow period may be a factor.

Nitrogen Application Methods

The application of fertilizer, and sowing of seed separately into soil using a double seed-and-fertilizer furrow-opener (ICRISAT Annual Report 1983, p. 259) requires higher draft power than a single furrow-opener through which combined seed and fertilizer are added. Also, if the fertilizer band is located too far from seed row, crop growth may be delayed. We therefore compared fertilizer application in a conventional side-band to that within the seed row, using urea and diammonium phosphate (DAP). We found that fertilizer application in the seed row, at the rate of 40-60 kg N ha^{-1}, gave better establishment of the sorghum crop and higher yields (Table 16). It is therefore feasible to use a single furrow-opener for combined placement of seed and fertilizers, at least in some situations.

Long-Term Soil Fertility Experiments

Three long-term experiments are in progress at ICRISAT Center. A summary of the results of the long-term potassium experiment was given last year, at the end of the first 4-year cycle (ICRISAT Annual Report 1983, pp. 260-265). The phosphorus experiment continues to give mean treatment effects that are in agreement with previous years, but increasingly there are trends to treatment x replicate interactions; these are being investigated.

In the 1983/84 season, the Cropping Systems and Soil Fertility and Chemistry subprograms initiated a new long-term experiment to investigate the effects of 2-year rotations on the long-term fertility of the soil, with diverse combinations of legumes and nonlegumes, and traditional and improved types of cropping systems. The results of the first 2-year cycle will be reported next year.

Table 16. Effect of method of application and type of fertilizer N on yields (kg ha^{-1}) of maize and sorghum on a Vertisol, and millet on a Vertic Inceptisol, ICRISAT Center, rainy and postrainy seasons 1983/1984.

Fertilizer N		Rainy season		Postrainy season
Type	Method of application[1]	Maize TDM (kg ha^{-1})	Millet grain (kg ha^{-1})	Sorghum grain (kg ha^{-1})
Nil	Nil	1150	370	700
Urea	Side-band	5180	650	1630
Urea	Seed-row	5980	740	2230
DAP	Side band	nd[2]	780	1890
DAP	Seed-row	6100	920	2420
SE		±901	±47	±325
CV (%)		21	11	33

1. All fertilizer N applied at seeding or sowing to millet (49 kg ha^{-1}) and sorghum (60 kg ha^{-1}). Maize given 80 kg N ha^{-1}, half at seeding (either side-band or seed-row), and half as side-band 4 weeks later.
2. nd = not determined.

Rainy-season crops such as soybean (right) and short-duration pigeonpea growing on a Vertisol ICRISAT Center, rainy season 1984. In ICRISAT's double-cropping system they will be followed in the postrainy season by sequential crops of chickpea, safflower, sorghum, or wheat that will benefit from the preceding legume.

Soil Management for Conservation

Rainfall Erosivity

The energy expended on soil by rainfall and runoff is the primary factor determining erosion by rainfall. Studies on storms—particularly the characterization of duration, intensity, and total amount of rainfall are needed to provide estimates of the erosivity of rainfall in a region. We commenced detailed measurements of storms at ICRISAT Center in 1983.

Figure 9 shows the intensity distribution for different sizes of storms in the 1983 rainy season. Many small storms (<25 mm) had mild intensities, without any prominent peak. Medium-sized storms (25-50 mm) usually started with high intensities, with another peak in the middle of the storm. Larger storms (>50 mm) had peak intensities halfway through the storm, followed by a 'tail' of much lower intensity. The highest rainfall/storm intensities recorded in the 1983 rainy season were 80 mm h^{-1} over a 15-min period on our Alfisol watershed, and 51 mm h^{-1} over a 15-min period on the Vertisol watersheds. The most frequent intensity sustained for 15 min ranged from 12-15 mm h^{-1}.

For each rain event, we calculated the total kinetic energy from the relationship between intensity and kinetic energy. The monthly totals of kinetic energy for different-sized storms are given in Table 17. Energy loads of individual storms of 1.5 μJ m^{-2} were common.

Table 17. Total kinetic energy (*μ* J m^{-2}) of storms of different size classes in Alfisol watershed, ICRISAT Center, 1983.

	Storm sizes (mm)					
Month	<13	13-25	26-37	38-50	>50	Total
Jun	0.0419	0.0998	-	-	-	0.1417
Jul	0.0841	0.0732	0.0712	-	-	0.0023
Aug	0.1052	0.1292	0.0521	0.0695	0.1072	0.4634
Sept	0.0934	0.0981	-	0.1345	0.1004	0.4265
Oct	0.0211	0.0837	-	0.0627	-	0.1676
Nov	0.0006	-	-	-	-	0.0006
Dec	0.0034	0.0170	-	-	-	0.0205
Total	1.6778	0.5010	0.1233	0.2667	0.2076	1.2226

The product of kinetic energy (E) of a storm, and its maximum rainfall intensity sustained for 30 min (I_{30}), gives an index of the erosivity of a rain storm. The total for the whole year provides a measure of the annual erosivity at a given

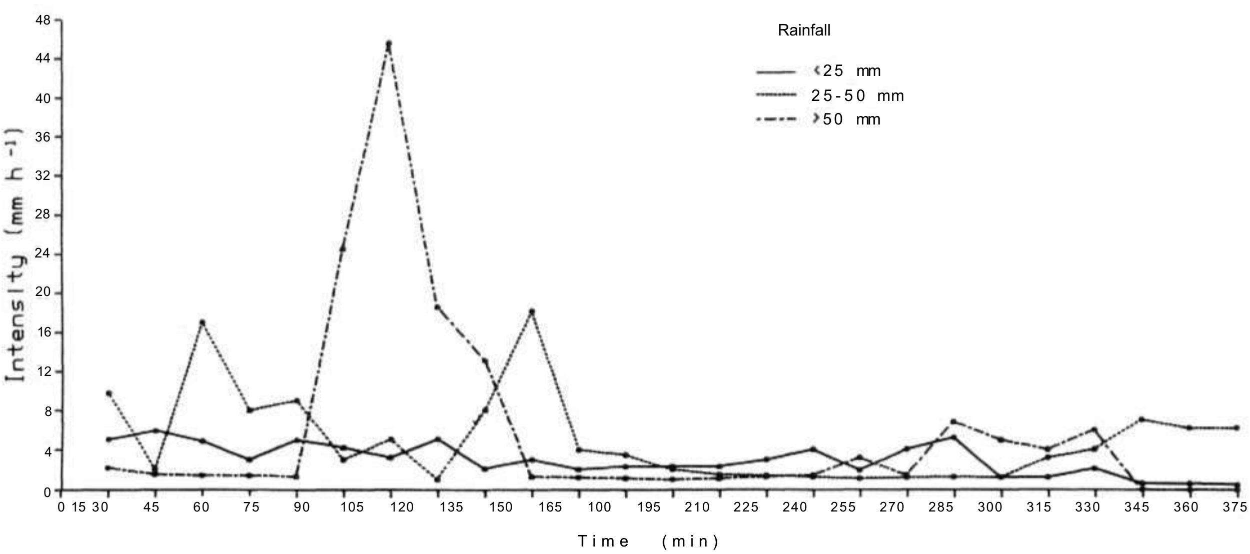


Figure 9. Temporal distribution of rainfall intensity during storms, for storm sizes of < 25, 25-50, and < 50 mm, Alfisol watershed, ICRISAT Center, 1983.

location; this is the R factor (EI_{30}) of the Universal Soil Loss Equation.

We calculated the erosivity index for different sizes of storms in the 1983 rainy season (Table 18). The distribution of EI_{30} during the year, for two locations at ICRISAT Center (Fig. 10), identified the most critical potential erosion period (August-September) and quantified the rainfall erosion hazard for this year. We need such analyses for long-term rainfall records to obtain an average rainfall erosivity.

The annual EI_{30} value of 484 indicates the total hazard for the year. This is low compared to global values on an annual basis, but considerable in the light of our short rainy season. We therefore suspect that EI_{30} may not be the best index of rainfall erosivity for the SAT. We will continue our studies on runoff and soil losses, and monitor storm characteristics so that we can determine the relationships between soil loss and rainfall-erosivity indices.

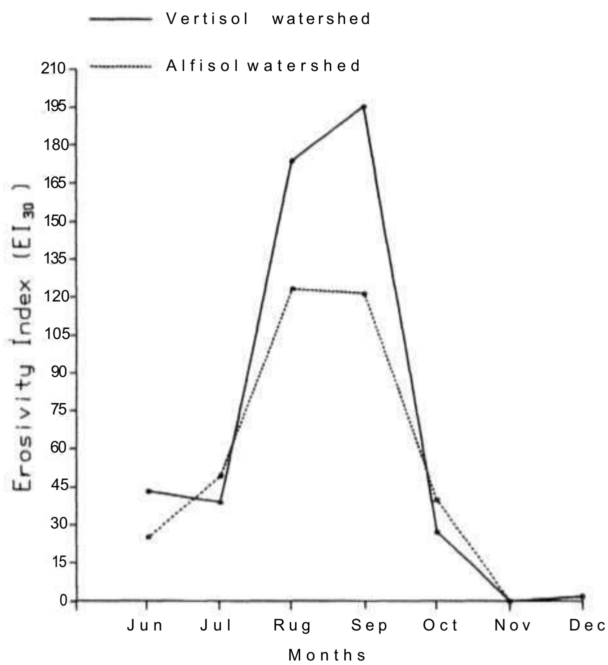


Figure 10. Monthly values of erosivity index EI_{30}, in Alfisol and Vertisol watersheds, ICRISAT Center, 1983.

Hydrological Modeling and Simulation

Vertisol Watersheds

Earlier we described a runoff model based on the modified curve-number technique, and a soil-moisture accounting procedure (ICRISAT Annual Report 1982, pp. 247-249). This model predicts soil-moisture content and daily runoff from small agricultural watersheds. We have now completed testing and calibrating the model for various land-management systems on the Vertisol watersheds at ICRISAT Center. About 10-15 runoff events are sufficient to estimate the two main parameters of the model.

Our earlier testing showed that the model was usually accurate for predicting runoff from Vertisol watersheds. However, for some individual

Table 18. Erosivity Index (EI_{30}) of rainfall in Alfisol watershed, ICRISAT Center, 1983.

	Storm size (mm)					
Month	0-12	12-25	25-37	37-50	>50	Total
Jun	5.5	38.1	-	-	-	43.6
Jul	11.3	11.6	16.2	-	-	39.1
Aug	14.5	37.2	16.9	54.5	50.6	173.7
Sept	11.7	30.4	-	-	-	198.3
Oct	3.5	10.5	-	13.5	-	27.4
Nov	0.1	-	-	-	-	0.1
Dec	0.1	2.0	-	-	-	2.1
Total	46.7	129.7	33.0	131.7	143.0	484.2
Annual EI_{30} (%)	10	27	7	27	29	100

storms, the model was not accurate, apparently because infiltration and runoff are improved by changes in soil-surface conditions. The smoothness of the land surface caused by earlier runoff events, and small cracks formed in the soil surface on drying during rainy season are two known factors. We have therefore modified the original runoff model to allow for the effects of such changes.

During extended rainless periods, the soil surface of Vertisols frequently develops many small cracks that markedly increase infiltration, and reduce runoff. The model estimates the negative contribution of cracks to runoff by:

$Sr = \alpha \sum^{n}_{1} E^*$, where

Sr = runoff 'cracking' adjustment factor (-mm), to be subtracted from predicted runoff for the next storm.

α = a function of the amount and type of clay in the soil, and represents the soil's inherent tendency to crack; it is determined by calibration with measured runoff data.

$\sum^{n}_{1} E^*$ = total evaporative demand on the soil during an extended rainless period.

n = the number of days with no rain or with rainfall less than soil evaporation.

This correction for cracking is applied only if the total evaporative demand ($\sum^{n}_{1} E^*$) exceeds 20 mm.

Depending on the amount of runoff, land becomes smoothed to varying degrees. Land smoothness created by a runoff event is described by:

$Ls = (Q_1)^{0.5} - 0.85$, where

Ls = smoothness correction (mm) created by a runoff event; it has a maximum value of 4.5 mm.

Q_1 = amount of previous runoff (mm).

The extent to which land smoothness from one storm affects runoff from the next storm depends on the relative magnitudes of the two runoff events. The contribution of land smoothness (Ls) to runoff is given by a factor (Rs) which relates to Ls as follows:

$Rs = Ls \times Q_2/Q_1$, where

Q_2/Q_1 = a utilization factor, whose maximum value is unity.

Q_1 = runoff from earlier storm causing the smoothness.

Q_2 = runoff on the day of calculation.

These two changes markedly improved the performance of the model in predicting the daily runoff (Table 19), as well as monthly and annual runoffs.

Alfisol Watersheds

We initially calibrated our model and tested it using hydrological data gathered from two deep-Alfisol watersheds at ICRISAT Center over the four years 1976-79. We used the 1978 data to calibrate the model, because we experienced the best range of storm sizes in this year; the other 3 years' data were used to test it. On Alfisols, 15-20 runoff events appear to be sufficient to accurately calibrate the model.

Table 19. Actual and predicted runoff with and without changes in soil surface conditions, deep Vertisol watershed, ICRISAT Center, 1976-79.

		Runoff (mm)		
			Predicted (mm)	
Year	Rainfall (mm)	Actual (mm)	Original model[1]	Modified model[2]
1976	110	27	36	28
1977	80	0	10	2
1978	216	170	160	167
1978	14	9	4	9
1979	32	6	5	6
1980	34	3	2	3
1980	207	108	90	102

1. Without corrections for fine cracks or land smoothness.
2. With corrections for fine cracks or land smoothness.

The model predicts annual runoff from two Alfisol watersheds (Table 20) with reasonable accuracy. It is also able to satisfactorily predict runoff for some individual large and medium runoff events from a broadbed-and-furrow (BBF) system (Table 21).

The model for Alfisols is less accurate for predicting some daily runoff events, especially when the soil surface has dried since the previous rain. The main reason seems to be the development of surface crusts which greatly reduce infiltration. We are developing a subroutine to make corrections for the effect of surface crusting.

Soil-Management Studies on Alfisols

Shallow Tillage

During the early part of a rainy season, Alfisols lose much of their rainfall in runoff causing appreciable soil loss. This occurs even when the soils are initially extremely dry and might be expected to rapidly absorb water. The high runoff on Alfisols is due to surface crusts, which are caused by the impact of raindrops on bare soil, and subsequent reorientation of fine soil particles. Shallow tillage to break the crust in addition to normal intercultivations for weed control improves infiltration, at least temporarily.

Table 20. Actual and predicted seasonal runoff (mm) from two deep-Alfisol watersheds, ICRISAT Center, 1976-79.

Land management system	Year	Rainfall (mm)	Runoff (mm)	
			Actual	Predicted
BBF	1976	685	191	179
0.6% slope	1977	563	80	98
	1978	1071	358	365
	1979	733	235	205
Flat cultivated,	1976	631	139	116
graded with bunds	1977	549	44	54
(0.6% slope)[1]	1978	1038	208	229

1. Runoff not recorded in 1979.

We measured the effect of shallow tillage, by additional interrow cultivations, on runoff and soil loss for three rainy seasons, 1981-83 (Table 22). Shallow tillage reduced seasonal runoff in

Table 21. Actual and predicted runoff (mm) from large- and medium-sized runoff events on an Alfisol watershed under BBF (0.6% slope) land management, ICRISAT Center, 1976-79.

Year	Rainfall (mm)	Runoff (mm)	
		Actual	Predicted
1976	169	98	89
	91	42	45
	25	10	9
1977	35	13	13
	52	17	20
1978	217	163	162
	51	17	19
	30	10	12
	28	6	6
	26	7	7
	25	8	9
1979	54	23	25
	52	31	37

Table 22. Effect of shallow tillage in addition to normal tillage for weed control, on runoff and soil loss from an Alfisol, ICRISAT Center, 1981-83.

Year	Tillage treatment	Rainfall (mm)	Runoff (mm)	Soil loss ($kg\ ha^{-1}$)
1981	Normal[1]	1092	246	5.0
	Additional[2]		223	4.9
	SE		±10.6	±0.34
1982	Normal	780	159	3.1
	Additional		120	2.6
	SE		±8.0	±0.33
1983	Normal	990	231	4.2
	Additional		196	4.0
	SE		±12.3	±0.24

1. Two inter-row cultivations.
2. Two additional shallow inter-row cultivations.

all three years but did not significantly reduce soil loss in any year. It increased cereal yields by 13-16% in 1982 and 1983 (Table 23). Shallow tillage did not increase crop yields in 1981, probably because high rainfall early in the rainy season eliminated the need for additional infiltration.

We conclude that, in years when early rains are poor, additional shallow tillage can be effective in increasing crop yields by promoting infiltration on Alfisols. Additionally, the loose top soil would also decrease evaporation loss during extended rainless periods.

Long-Term Effects of Subsoiling an Alfisol

Tillage research on Alfisols in the past has shown that the effect of tillage is not long lasting, because of the rapid development of a crust on the soil surface. Crusts limit crop yields by reducing emergence and rainfall infiltration into the soil. However, we suspect that compact subsoil layers may also limit crop yields and that loosening the subsoil may have a longer-term effect than surface tillage.

We started an experiment to evaluate the long-term effect of subsoiling an Alfisol. For this, we used conventional deep rippers drawn by heavy tractors; the ripping tines, spaced 1 m apart, shattered the soil to a depth of 50-60 cm but did not invert it. We tried three subsoiling treatments: normal tillage (T_1), normal tillage with subsoiling every year (T_2), and normal tillage with subsoiling every 3rd year (T_3). We started the experiment in 1984 by subsoiling T_2 and T_3, then tilling the soil in all treatments in the usual way prior to sowing maize (Deccan Hybrid 103) on 19 June; we harvested the crop on 25 September. We measured TDM, grain yield, leaf area, soil bulk density, root density, and rainfall infiltration.

Total rain during the cropping period was 334 mm; drought stress severely limited crop growth, resulting in low yields of grain and TDM. Subsoiling increased grain yield from 280 kg ha^{-1} in T_1 to 510 kg ha^{-1} for the mean of T_2 and T_3 (SE = ± 87), and TDM from 1590 to 2290 kg ha^{-1} (SE = ± 122). Subsoiling increased LAI significantly ($P < 0.05$) at 50 DAE (Fig. 11) and consistently increased ($P < 0.10$) TDM (Fig. 12).

Subsoiling resulted in better root proliferation, especially at greater depths (Table 24). But we could not detect increased soil bulk density, which was measured at 10-cm depth increments similar to the samplings for root density. Bulk density values for the various depths ranged from 1.66 to 1.77 g cm"^{3} in the conventionally tilled profile, and 1.48 to 1.72 g cm^{-3} in the subsoiled profile.

We measured water infiltration into the soil

Table 23. Effect on grain yield (kg ha^{-1}) of shallow tillage in addition to normal tillage for weed control, Alfisol, ICRISAT Center, 1981-84.

	Grain yield (kg ha^{-1})			
	1981-82	1982-83		1983-84
Tillage treatment	Sole sorghum	Intercrop sorghum	Intercrop pigeonpea	Sole pearl millet
Normal[1]	2350	2260	925	2620
Additional[2]	2360	2620	930	2970
SE	±50	±25	±41	±32

1. Two inter-row cultivations.
2. Two additional shallow inter-row cultivations.

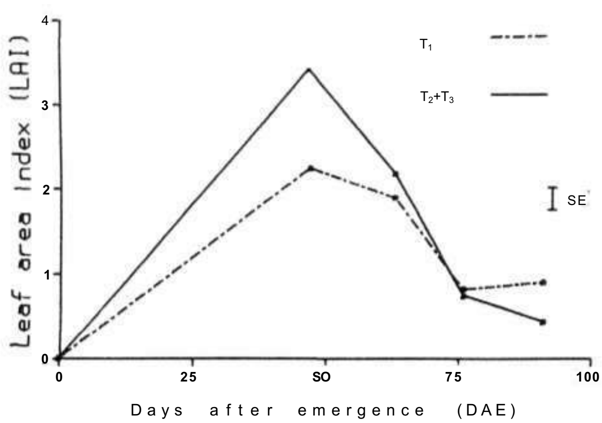


Figure 11. Effect of subsoiling an Alfisol on leaf area index (LAI) of maize, ICRISAT Center, rainy season 1984.

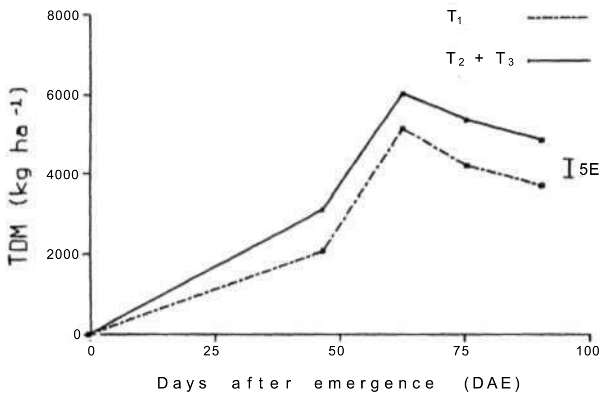


Figure 12. Effect of subsoiling an Alfisol on total dry matter (TDM) production of maize (kg ha^{-1}), ICRISAT Center, rainy season 1984.

Table 24. Effect of subsoiling on root density (cm cc^{-1}) at 89 days after emergence (DAE) of maize (cv Deccan Hybrid 103) on an Alfisol, ICRISAT Center, rainy season 1984.

Soil depth (cm)	Root density (cm cc^{-1})		
	Subsoiling	Normal tillage	SE
0-10	0.55	0.42	±0.072
10-20	0.29	0.21	±0.022
20-30	0.20	0.09	±0.034
30-40	0.15	0.10	±0.028
40-50	0.12	0.06	±0.016
50-60	0.14	0.05	±0.039

during the dry season, one month after harvest. Subsoiling increased infiltration (Fig. 13). The steady-state infiltration rates 150 min after the start of infiltration measurements were 0.3 ± 0.0 cm h^{-1} for the conventionally tilled treatment, and 1.4 ± 0.55 cm h^{-1} for the subsoiled treatments and the accumulated amounts of water infiltrated at this time were 4.1 ± 0.97 cm for T_1 and 8.6 ± 2.37 for T_2 and T_3. Because the effect of subsoiling persisted throughout this first rainy season, and there is usually very little rain after the end of the southwest monsoon, we expect that the subsoiling will still be effective at the beginning of the next rainy season.

Limited Irrigation for Rainy-Season Crops

Dryland cropping on Alfisols is generally restricted to the rainy season, because their low water-holding capacity does not provide sufficient moisture to support crops for long after the rains cease. Even during the rainy season, crops commonly experience mild to severe drought stress depending on variations in the amount and distribution of rainfall. Supplementary irrigation could increase crop yields substantially. Water could be made available for irrigation by collection of that part of the rainfall that is lost as runoff (20-25%, on average). Strategies would then be needed to schedule irrigations to optimize crop production. Irrigating only a fraction of the total land area has been proposed as a means to improve the overall within-field use of rainfall, runoff, and irrigation water.

The limited-irrigation dryland (LID) concept—developed by Texas A&M University for optimum use of limited amounts of irrigation water to supplement rainfall—involves the division of a field by its slope into three sections, each with a distinct water regime. The uppermost section is conventionally irrigated; the middle section receives partial irrigation from 'tail water runoff, i.e., excess water from the uppermost section; the lowest section is managed as dryland, but receives normal rainfall runoff, and

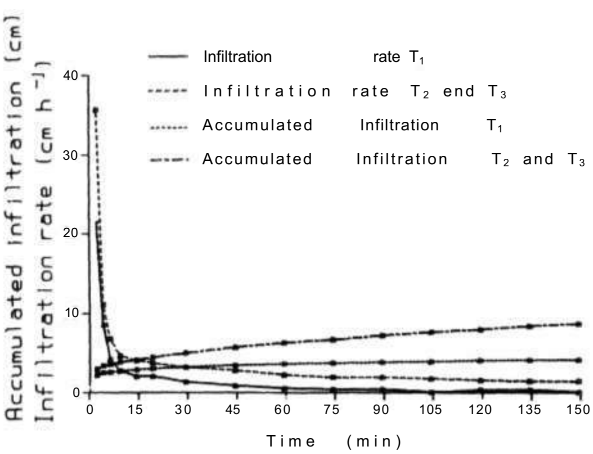


Figure 13. Effect of subsoiling an Alfisol on infiltration rate and accumulated infiltration, ICRISAT Center, rainy season 1984.

perhaps some irrigation runoff from the upper sections. These different water-regime management sections may require different cropping systems, sowing densities, and fertilizer rates. We therefore initiated management experiments on an Alfisol in the 1984 rainy season.

In early July, we sowed two sorghum cultivars (SPV 351 and SPH 221) at three population densities (60, 120, and 180 x 10^3 plants ha^{-1}, and applied N and P fertilizers at three levels (55N:20P, 120N:30P, and 200N:50P in kg ha^{-1}) to each of the LID irrigation regimes. These consisted of consecutive 20-m long strips irrigated as described above. Runoff volume from each section was measured using a multislot divisor. We began recording runoff on 9 August, and harvested the sorghum on 17 September.

Between sowing and harvest only 435 mm rain fell. None fell between 10 August and 10 September and the dryland section did not receive any water during this time. Of the total 255 mm water applied to the irrigated section, only one-third was retained by the soil, and the remaining 167 mm was lost as runoff to the tail-water runoff section; no irrigation runoff from the top section reached the dryland section. On the top and middle sections, about 50% of the rainfall was retained by the soil and the remainder lost as runoff. More rainfall (68%) infiltrated into the soil of the lowest section, thus its runoff loss was lower.

As expected, especially for a season with a prolonged mid-season drought, irrigation markedly increased sorghum grain yield and its response to fertilizer inputs and population density (Table 25). In the irrigated section, SPH 221 grain yield exceeded 4000 kg ha^{-1} at all 3 population densities for the two higher fertilizer levels, which on average increased yield by 70% over that of the lowest fertilizer level. SPV 351 yielded less, and responded less to fertilizer. Responses to fertilizer were lower in the tail-water runoff

Table 25. Effect of three irrigation regimes on grain yield (kg ha^{-1}) of two sorghum cultivars grown at three population densities with three levels of added fertilizer, Alfisol, ICRISAT Center, rainy season 1984.

		Cultivar					
		SPV 351			SPH 221		
		Population (10^3 ha^{-1})			Population (10^3 ha^{-1})		
Irrigation regime	Fertilizer level[1]	60	120	180	60	120	180
Irrigated	F_1	2560	2530	2710	2460	2220	3700
	F_2	3280	3540	3700	4290	4310	4780
	F_3	4400	3130	3260	4890	4620	5110
SE		±257					
Tail-water runoff	F_1	2950	1930	3260	2980	3180	4020
	F_2	3660	3870	3640	3920	4580	4740
	F_3	3870	3200	3260	3760	4340	4390
SE		±322					
Dryland	F_1	2140	2570	2460	2780	2930	3090
	F_2	2260	2750	2700	3240	3310	3240
	F_3	2220	1840	2820	3140	2470	3640
SE		±292					

1. F_1 = 55 kg N and 20 kg P ha^{-1}.
F_2 = 120 kg N and 30 kg P ha^{-1}.
F_3 = 200 kg N and 50 kg P ha^{-1}.

section, and were not statistically significant for the dryland section. On the two better-watered sections, increased population density tended to increase yield of SPH 221, but not of SPV 351; lower population densities however, did not increase crop yields on the dryland section, which could have been expected in such a dry year.

These preliminary results show that implementation of the LID concept therefore requires different crop management to match the different soil-moisture regimes. Low population densities and low fertilizer inputs are adequate for the dryland section. But the improved water regime on the irrigated and tail-water runoff sections will merit higher inputs of nutrients depending on soil nutrient status and, depending on cultivar characteristics, could perhaps support higher plant populations.

Recycling Runoff

Windmill Evaluation

In 1983 and 1984, we made preliminary operational tests on a windmill, because this is a low-cost method of recycling runoff water from our watersheds. The windmill was designed and manufactured by the Institute of Engineering and Rural Technology, Allahabad, and was supplied by the Commission for Additional Sources of Energy, Department of Science and Technology, New Delhi, through the Rural Electrification Branch of Andhra Pradesh Electricity Board, to test its performance at ICRISAT Center.

We installed the windmill so that it could supply an orchard with water from a nearby tank, which provided a regular supply of water throughout the year at an average head of 6m. We measured the total volume of water pumped, and the total run-of-wind, between August 1983 and March 1984, except when repairs were necessary for brief periods in September and December 1983, and January 1984. Daily output fluctuated considerably because of variations in average wind velocity (Fig. 14). However, average pumping discharge rate was high even on days when the average wind velocity was quite low. The performance was quite satisfactory with an average output over the entire period of about 4000 L h^{-1} for an average wind speed of approximately 7.5 km h^{-1}.

The windmill pumped sufficient water for

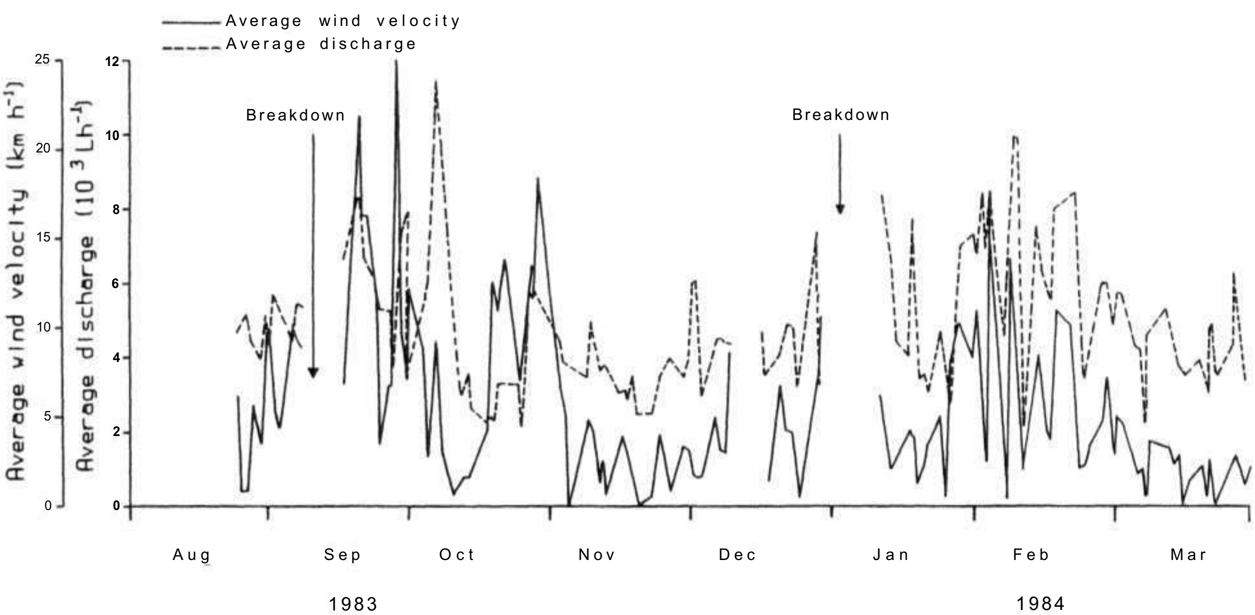


Figure 14. Average discharge rate of a wind-operated water pump, and average wind velocity, ICRISAT Center, September 1983-March 1984.

weekly irrigations of tomatoes (local) and maize (Deccan Hybrid 101) grown on 0.7 ha of land during the postrainy season 1984. The yields were 3600 kg ha^{-1} maize and 8560 kg ha^{-1} tomatoes.

Further evaluations of pumping efficiency require continuous recordings of pumping rate and wind speed. Probability analysis of the wind speed would allow us to calculate the reliability of water output.

Preliminary testing of the wind pumping system revealed a number of operational problems:

1. Pump maintenance was difficult, because it was below water-level. We therefore raised the pump to ground level,and installed a flexible suction pipe fitted with a suitable foot valve.
2. Excessive wear in a number of the moving parts in the drive mechanism from the rotor indicated the need for replacement with alternatives made from harder steel.

Evaluation of Low-Cost Tank Sealants

Earlier, we examined the performance of various linings for 1.3 m^3-small pits in an Alfisol with a low content (15%) of fine particles (silt plus clay). Seepage rates were high. Lining the pond with a 10:1 soil/cement mixture reduced the seepage rate by about 97%. This lining performed consistently well while the pit was kept continuously filled with water. But after emptying and allowing the lining to dry, it developed cracks, thus reducing its effectiveness.

We examined treatments designed to minimize seepage rates, by controlling the cracking of the soil/cement lining in intermittently-filled pits. We determined terminal seepage rates in 4 unlined pits from daily seepage measurements over a 15-day period. On these calibrated pits, we then imposed the following lining treatments:

- P_1. Control (unlined)
- P_2. Lined with plain soil/cement lining (no contraction joints)
- P_3. Soil/cement mixture laid in 40 x 40 cm blocks, leaving a 2-cm wide contraction joint later filled with asphalt.
- P_4. Plain soil/cement mixture laid as a smooth lining; scored to half the lining depth when moist to create 0.5-cm wide contraction joints later filled with asphalt on a 40 x 40 cm grid.

After applying the lining treatments, we kept the four pits filled with water and monitored the seepage rate daily for 15 days. We then emptied the water from the pits, and allowed the linings to dry for 30 days. We imposed 2 subsequent cycles of seepage measurement for 15 days followed by drying for 30 days.

The smooth soil/cement lining (P_2) developed 1- to 3-mm wide cracks. The contraction joints almost completely prevented cracking between the joints in P_3 and P_4. The seepage-rate measurements (Table 26) show that soil/cement lining with 0.5-cm wide asphalt-filled contraction joints (P_4) performed best; laying soil/cement blocks separated by 2-cm wide asphalt-filled contraction joints was not any more effective for seepage control than the cement lining with scored contraction joints for control of cracking.

On-Station Operational Research

Equipment Development

Pesticide Sprayer

Conventional knapsack sprayers require large volumes of water, up to 400-600 L ha^{-1} of spray solution, which causes considerable hardship to SAT farmers because they usually have to carry clean water long distances. Reduction in the amount of water needed to apply pesticides is highly desirable. We began testing, in cooperation with Cropping Systems Entomology, the low volume (LV), and an ultra-low volume (ULV) sprayer mounted on a bullock-drawn wheeled tool carrier (WTC).

Table 26. Effect of various soil/cement lining treatments on reducing seepage from small pits in an Alfisol, ICRISAT Center, 1983.

Pit no.	Lining: Material	Lining: Joints	Calibration[1]	Terminal seepage rate (mm day^{-1}) Fillings: 1st	2nd	3rd	Reduction in seepage rate (%) Fillings: 1st	2nd	3rd
P_1	-[2]	-[2]	192	190	192	189	1	0	2
P_2	10:1 Soil/cement laid smooth	-	190	6	15	15	97	92	92
P_3	10:1 Soil/cement, laid in 40 x 40 cm square blocks	2 cm, asphalt-filled	178	18	25	28	90	86	84
P_4	10:1 Soil/cement laid smooth and scored[3]	0.5 cm, asphalt-filled	185	7	8	7	96	96	96

1. Measured before imposing lining treatments.
2. - = not used.
3. Slits erected by scoring lines to half-depth on a 40 * 40 cm grid.

These two sprayers differ in the mechanism used to produce the small droplets necessary to achieve good plant coverage, using very small volumes of spray mix per hectare. In the LV sprayer, the spray mix is forced at high pressure through a fine jet; in the ULV sprayer, a trickle of spray falls on to a rapidly-spinning disc, that throws off uniform-sized droplets. Droplet size can be controlled by changing the disc's rotation speed, hence its alternate name—controlled droplet applicator (CDA). The LV sprayer can work effectively with as little as 70 L spray ha^{-1}, but has the disadvantage that its very fine jets are prone to blockages. The ULV sprayer has the combined advantage that the amount of spray solution can be reduced to less than 10 L ha^{-1}, and jet blockages are less common.

Both spray units were mounted on a WTC with a 4.5-m wide spray boom that could be adjusted to spray at heights from 65 to 235 cm from the ground. The LV sprayer has 6-8 jets per boom, and a chain from one wheel drives the reciprocating pump that delivers spray solution to the spray nozzles at a pressure of 275 kPa. The nozzle used to spray pesticide onto 3 rows of pigeonpea is shown in Figure 15. For the ULV spray we mounted 3 spinning-disc assemblies (American Spring and Pressing Works, Bombay) on the boom. The spinning-disc assemblies were driven by electric motors, powered by a 6 V car battery with sufficient charge to operate continuously for half a working day.

We began tests on both sprayers in a 3-ha pigeonpea field at ICRISAT Center, and on the ULV sprayer at our on-farm research location at Farhatabad, Karnataka. Both machines had a field capacity of approximately 0.85 ha h^{-1}, and their efficiency in controlling *Heliothis armigera* is being assessed.

Planter Development

We previously concentrated on improving seeding and fertilizer equipment attached to a WTC such as the Tropicultor or Nikart (ICRISAT Annual Report 1983, pp.268-272). Farmers, however, want a simple bullock-drawn machine that they can easily adjust and use, to sow their crops and apply fertilizer, without having to buy a separate WTC. Based on farmers* comments, we initiated the development of an independent planter.

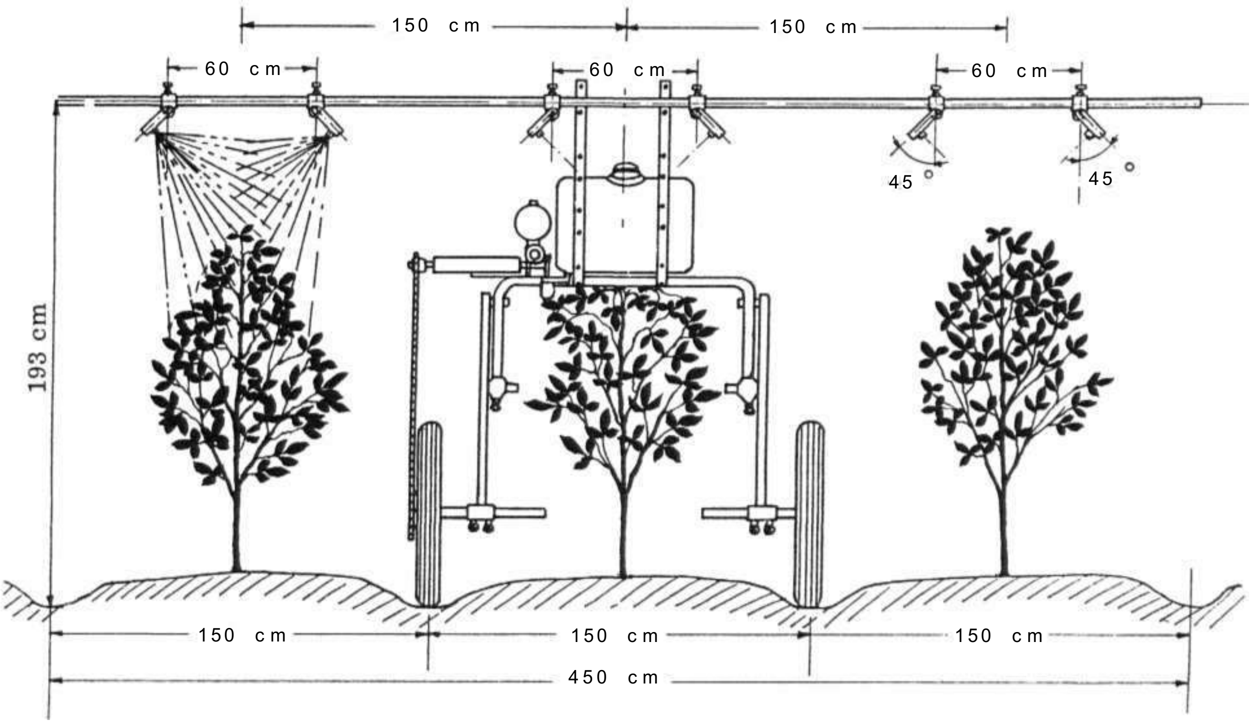


Figure 15. Nozzle arrangement for spraying pigeonpea with the LV sprayer.

Figure 16. Trainee from Mali watching the independent planter and fertilizer applicator in operation on a Vertisol, ICRISAT Center, 1984.

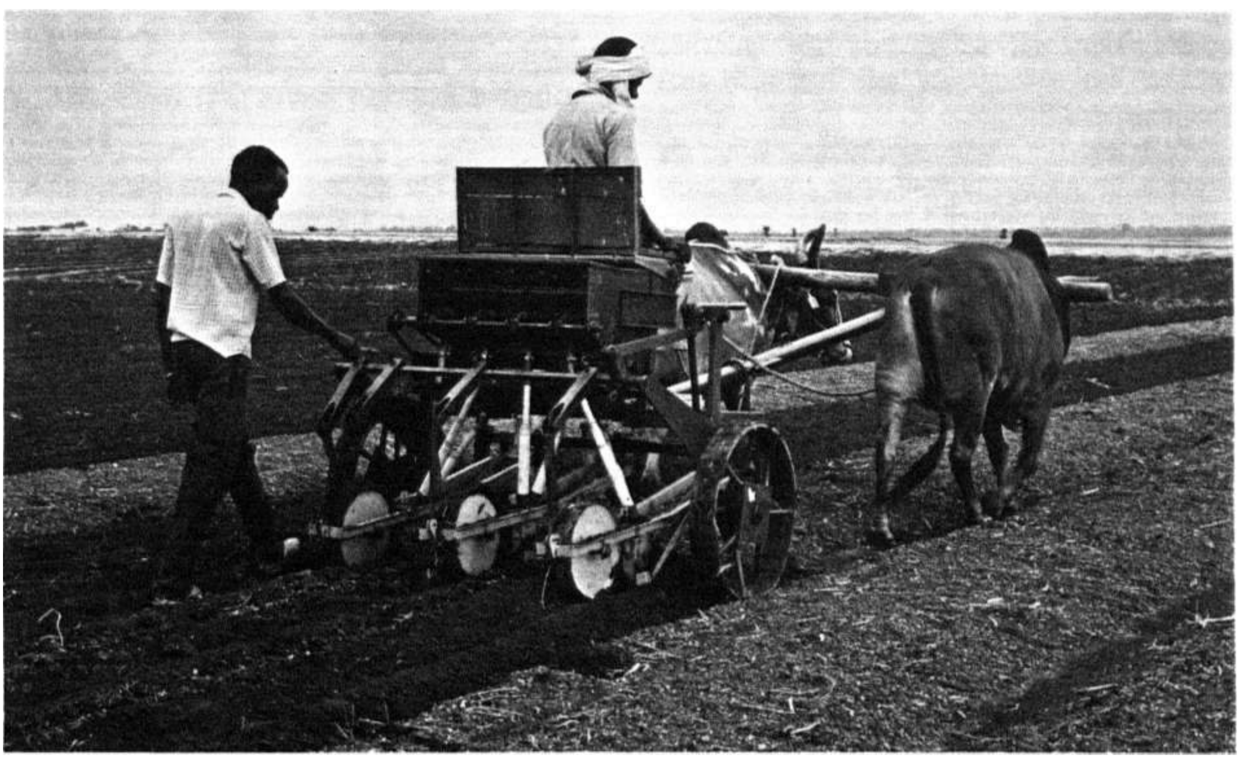


Figure 16 shows a planter developed and tested at ICRISAT Center for sowing rainy-and postrainy-season crops. This unit has a simple light frame made from hollow square and rectangular steel sections, and is supported on two 60-cm diameter steel wheels. Fertilizer and seed fall from a two-sectioned hopper onto the furrow openers through telescopic tubes made of plastic to minimize weight and corrosion. Each of the double-furrow openers can 'float', thus allowing a uniform depth of seeding on uneven land, because they are pivoted on a hollow square bar in the front of the planter.

We tested the planter's performance sowing five crops—groundnut, maize, sorghum, pigeonpea, and chickpea on an experimental scale, and its robustness and flexibility on an operational scale.

For all crops except chickpea, we achieved stand establishments close to the recommended plant populations (Table 27). At least 50% of the plants were within the required spacing limits, and excluding chickpea, over 75% were within the limits of a 'good' spacing (Figs. 17a-e). The appreciable number of plants with spacings two to three times greater than the mean were caused by failure of 10-20% of seeds to emerge. The results were not satisfactory for chickpea because our sowing rate was less than that recommended.

We tested the endurance of the planter by using it on an operational scale to sow large areas of land. We sowed 5 ha in the rainy season and 15 ha in the postrainy season with two machines. The crops sown were sole sorghum, maize, chickpea, and safflower, and a sorghum/ pigeonpea intercrop.

Applying fertilizer (left) and seed (right) using an attachment to the bullock-drawn Agribar, Vertisol watershed, ICRISAT Center, rainy season 1984.

Table 27. Plant population achieved for five crops sown using a low-cost planter, Vertisol, ICRISAT Center, postrainy season 1984.

Crop	Cultivar	Population recommended (ha^{-1})	Seeds sown (ha^{-1})	Population achieved (ha^{-1})
Groundnut	Robut 33-1	330000	370000	317000
Maize	Deccan 103	60000	59000	54000
Sorghum	CSH 5	180000	270000	180000
Chickpea	Annigeri	330000	317000	272000
Pigeonpea	ICP 16	50000	83000	59000

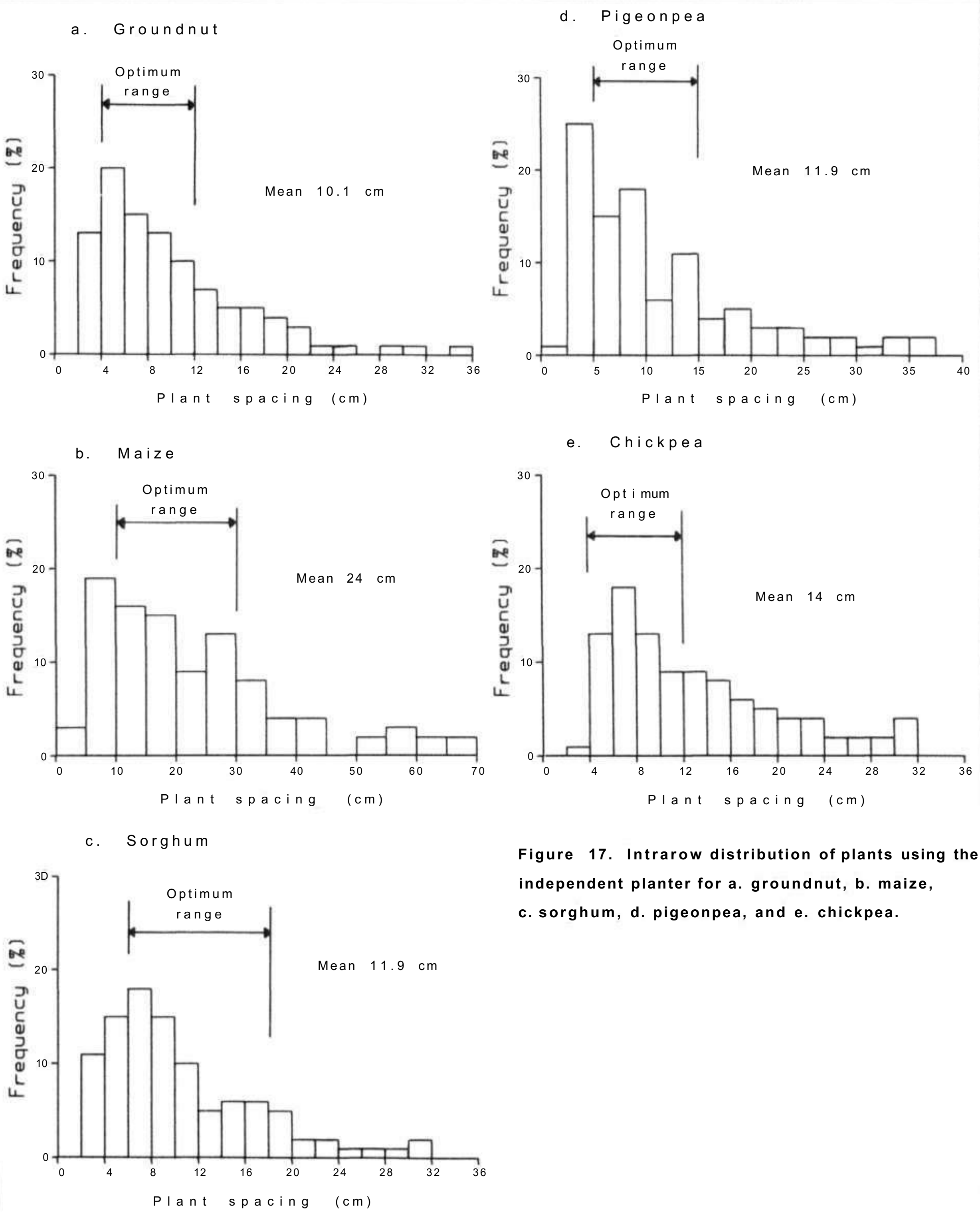


Figure 17. Intrarow distribution of plants using the independent planter for a. groundnut, b. maize, c. sorghum, d. pigeonpea, and e. chickpea.

The planter's overall performance was very satisfactory. It could sow one ha in 4 to 6 h on the BBF system. We will make further tests on an operational scale at our on-farm locations.

We have prepared a complete set of engineering drawings of the planter, and supplied these to one manufacturer in India for limited production. Machines from this manufacturer will be used for on-farm testing.

Low-Cost Toolbar

We initiated development of a simple toolbar to provide a cheaper alternative to the Tropicultor or Nikart for the SAT farmer. The resultant Agribar is lighter in weight (only 80 kg), simple in construction, and easy to handle, but does not sacrifice the versatility of a WTC (Fig. 18). The implements used with the Agribar are interchangeable with those for the Tropicultor and Nikart. The operator can ride on it, providing additional weight to improve stability for heavy operations.

Initial test results of the Agribar were given in ICRISAT Annual Report 1981, p. 248. Following endurance tests to identify the likely weaknesses in the components, we made a number of small design alterations. The present design has been used continuously for the post-harvest field operations of plowing and ridging in the ICRISAT Vertisol watersheds.

We are also testing the Agribar under different agroclimatic conditions in West Africa, where ICRISAT scientists are using it for their field-scale experiments. At present, testing is limited to Mali, but will soon be extended to the ISC in

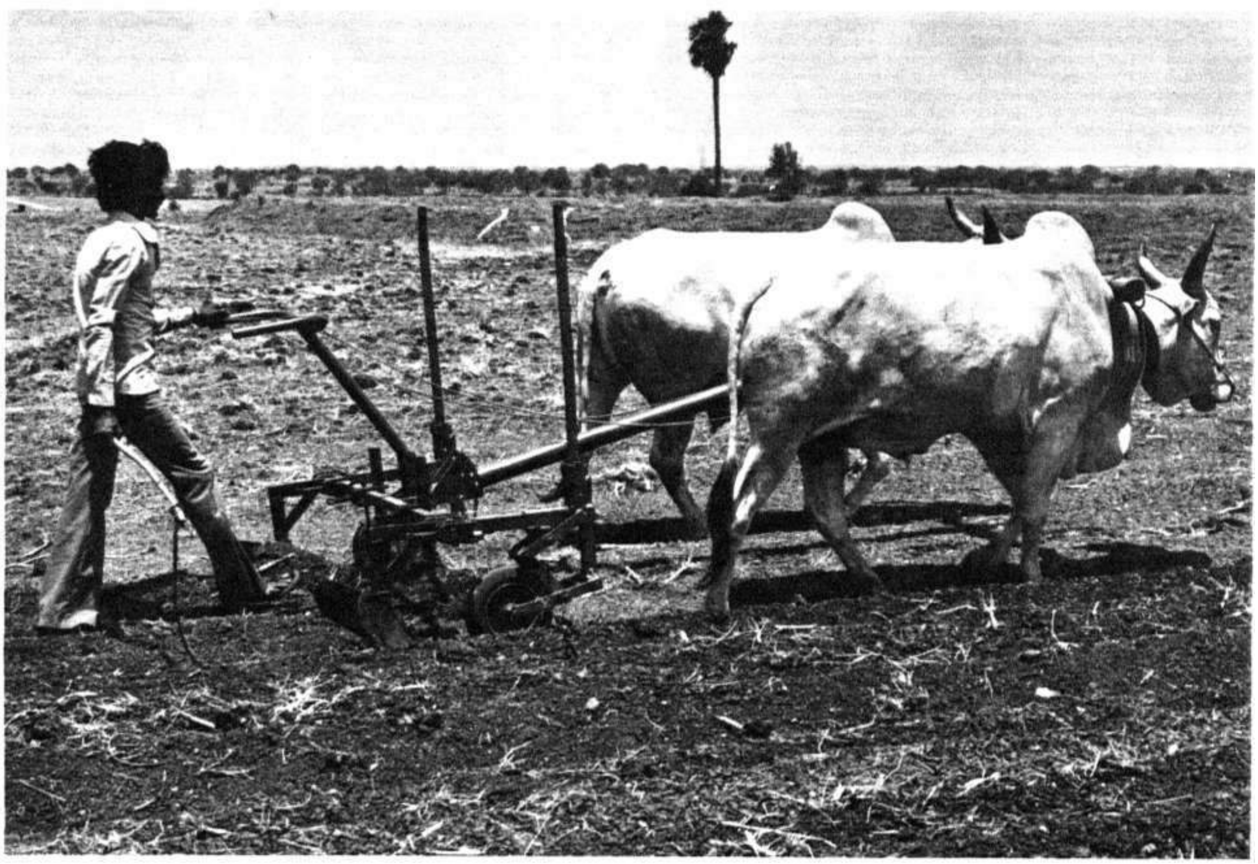


Figure 18. Low-cost toolbar (Agribar) with two ridgers and a blade harrow, forming broadbeds on a Vertisol, ICRISAT Center, 1984.

Niger. We also intend to test the Agribar in farmers' fields in India as part of our on-farm research.

Cropping Systems for Different Soils

We continued operational-scale experiments initiated in 1982 to evaluate cropping systems options for different soils in the research watersheds at ICRISAT Center. We used large plots (200-400 m^{-2}), the WTC, and BBF system, so that we could assess operational feasibility; costs were calculated to assess economic viability. Two fertilizer levels were included as main plots in a split-plot layout, with the different cropping systems as subplots; there were three replications. On all soils—deep (1,5 m), medium-deep (1.0 m), and shallow (0.5 m) black soils, and Alfisols (0.5-1.0 m)—we compared the two fertilizer treatments: 'no added fertilizer', and 60 kg N plus 12 kg P ha^{-1}. The systems being examined changed little from the two previous years (ICRISAT Annual Reports 1982, p. 274 and 1983, p. 265). Yields and net returns are given in Figures 19-22.

Deep Black Soils

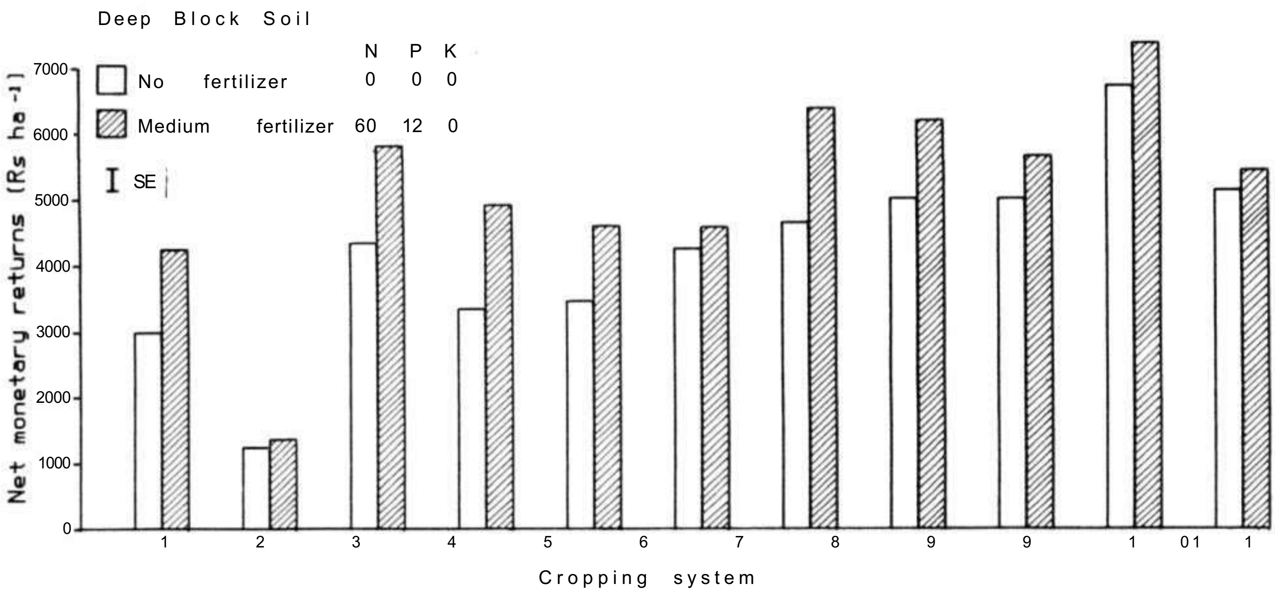
Sesamum was included this year in an intercrop system (sesamum/pigeonpea) because of its potential importance on deep black soils (particularly for the more marginal-rainfall areas in Karnataka). An early pigeonpea (ICPL 87) followed by ratooned pigeonpea was also included because of its promising performance on deep black soils, as reported by ICRISAT pulse physiologists in recent years (ICRISAT Annual Report 1983, p. 171). Of the 11 cropping systems evaluated, five were intercrops and six sequential crop systems.

Sorghum grain yields again exceeded maize yields, especially without fertilizer (Fig. 19). Averaged over the sequential and intercrop systems, sorghum yield was 1170 kg ha^{-1} compared with 720 kg ha^{-1} for maize without fertilizer, and 2090 kg ha^{-1} compared with 1780 kg ha^{-1} with medium fertilizer input. As in 1982 we found that the higher cereal yields with medium fertilizer inputs in cereal/pigeonpea intercrops did not cause a reduction in pigeonpea yields. Of the rainy-season legumes, soybean yields were again much higher than either mung bean or cowpea, confirming soybean's considerable potential as a high-yielding, rainy-season alternative to cereals. The response of legumes to fertilizer inputs was much lower than that of cereal crops, confirming results in the previous two years.

Considering the net returns (Fig. 19), 9 of the 11 systems gave more than 3000 Rs ha^{-1} with no fertilizer input. All pigeonpea-based intercrops gave higher returns than sequential crops without added fertilizer. With medium fertilizer inputs, 9 of the 11 systems gave net returns of more than 4500 Rs ha^{-1}. As in 1982, the soybean/ pigeonpea intercrop again gave the highest net returns with low and medium fertilizer inputs. Of the sequential systems, the soybean-sorghum sequential crop gave the highest returns. The sesamum/pigeonpea intercrop, newly included this year, proved to be a good alternative intercrop option. Early pigeonpea produced a very good yield in the rainy season, similar to that of soybean; but its ratoon yield was not satisfactory. This could be a good alternative pulse crop option for the rainy season, provided genotypes that mature still earlier (in 100 to 120 days) than the one used currently (about 140-150 days) are available to permit sequential, postrainy-season crops to be sown before the rains recede in early October.

Medium-Deep Black Soils

All the six cropping systems evaluated during 1982/83 were further tested in 1983/84. We used three intercrop systems: sorghum/pigeonpea, maize/pigeonpea, and mung bean/cotton, and three sequential systems: sorghum-chickpea, sorghum-safflower, and mung bean-sorghum. An additional system this year was early pigeonpea in sequentially cropped pigeonpea-sorghum. This was considered an improvement over the mung bean-sorghum system, because early pigeonpea at high plant-population densities is potentially much more productive than mung



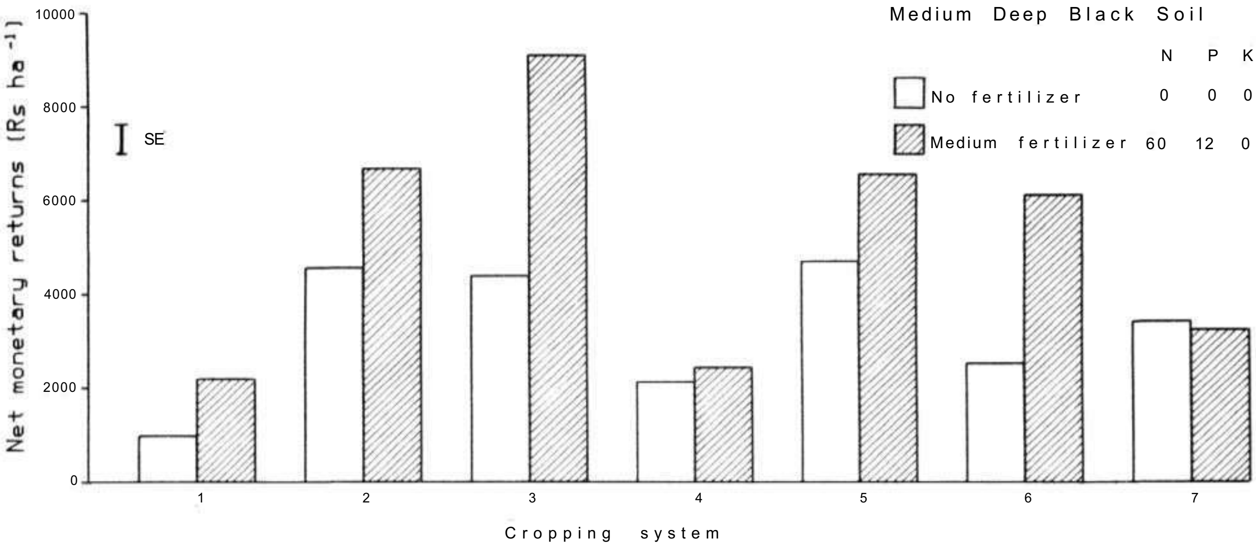
Fertilizer rate	1	2	3	4	5	6	7	8	9	10	11
	Rainy-season yield (kg ha^{-1})										
	MB-	MB-	SB-	Mai-	Sor-	EPP	Sor/	Mai/	Cop/	SB/	SM/
Nil	370	300	1100	780	1230	1120	1100	660	420	1160	430
Medium	450	430	1220	1890	2190	1250	2000	1670	1250	1370	450
	Postrainy-season yield (kg ha^{-1})										
	Seq Sor	Seq Chi	Seq Sor	Seq CP	Seq SF	Rat	IC PP	IC PP	IC PP	IC PP	IC PP
Nil	1260	480	1100	1030	730	140	1010	1240	1220	1030	1020
Medium	2040	570	1900	1300	900	170	1280	1330	1450	1050	1190

(CP = chickpea, Chi = chillies, Cop = cowpea, EPP = early pigeonpea, Mai = maize, MB = mung bean, PP = pigeonpea, SF = safflower, SM = sesame, Sor = sorghum, IC = intercrop, Rat = ratoon, Seq = sequential crop)

Figure 19. Net monetary returns (Rs ha^{-1}) and grain yields (kg ha^{-1}) from indicated cropping systems (1-11) grown on an operational scale on a deep black soil (Vertisol) with nil and medium fertilizer inputs, ICRISAT Center, rainy and postrainy seasons 1983.

bean. However, during the year, early pigeonpea maturity was so delayed by the mid-season drought that the sorghum could not be sown because the soil was too dry. We therefore ratooned the early pigeonpea at maturity to give a second harvest.

As in the previous two years, the cereal/pigeonpea intercrop and the sorghum-chickpea and sorghum-safflower sequential systems gave high returns (Fig. 20). High yield and high market prices for safflower this year made the sorghum-safflower sequential system the most profitable system with added fertilizer inputs. Without fertilizer inputs, the poor maize yield was not sufficiently compensated by improved yield of the pigeonpea intercrop; the overall performance of the maize/pigeonpea intercrop was disappointing compared to that of the other three cereal-based systems. Returns from the mung bean/cotton intercrop and mung bean-sorghum sequential cropping systems were much lower compared to the four systems dis-



Fertilizer rate	1	2	3	4	5	6	7
	Rainy-season yield (kg ha^{-1})						
	MB-	Sor-	Sor-	MB/	Sor/	Mai/	EPP
Nil	240	2180	2390	180	2440	680	650
Medium	280	3890	4460	160	3370	2930	710
	Postrainy-season yield (kg ha^{-1})						
	Seq Sor	Seq CP	Seq SF	IC Cot	IC PP	IC PP	Rat
Nil	550	850	570	650	580	610	320
Medium	1400	1020	1280	810	860	860	350

(CP = chickpea, Cot = cotton, EPP = early pigeonpea, Mai = maize, MB = mung bean, PP = pigeonpea, SF = safflower, Sor = sorghum, IC = intercrop, Rat = ratoon, Seq = sequential crop)

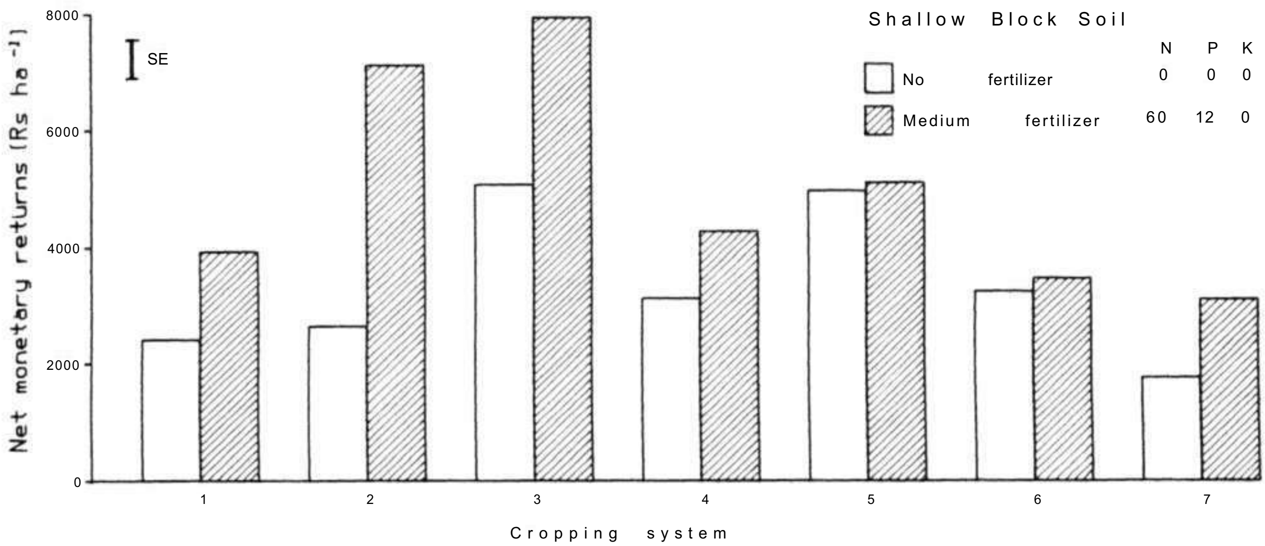
Figure 20. Net monetary returns (Rs ha^{-1}) and grain yields (kg ha^{-1}) from indicated cropping systems grown on an operational scale on a medium-deep black soil with nil and medium fertilizer inputs, ICRISAT Center, rainy and postrainy seasons 1983.

cussed above. In contrast to the promising performance shown in earlier experiments at ICRISAT Center, early pigeonpea (ICPL 87) gave ratoon yields well below our expectations in this year's operational-scale evaluation. We will evaluate early pigeonpea ratooning further in 1984/85 with ICPL 87, and will explore the possibility of growing sorghum sequentially after pigeonpea, using a shorter-duration genotype than the one we used this year.

Shallow Black Soils

All six cropping systems evaluated in 1982/83 were further tested in 1983/84. Four of these systems involved a medium-duration pigeonpea (ICP 1-6) used as a sole crop in one system, and as an intercrop in three others. The remaining two systems had mung bean intercropped with either sorghum or castor. In 1983 we also evaluated an additional cropping system, an early pigeonpea (ICPL 87) ratooned to give a second harvest.

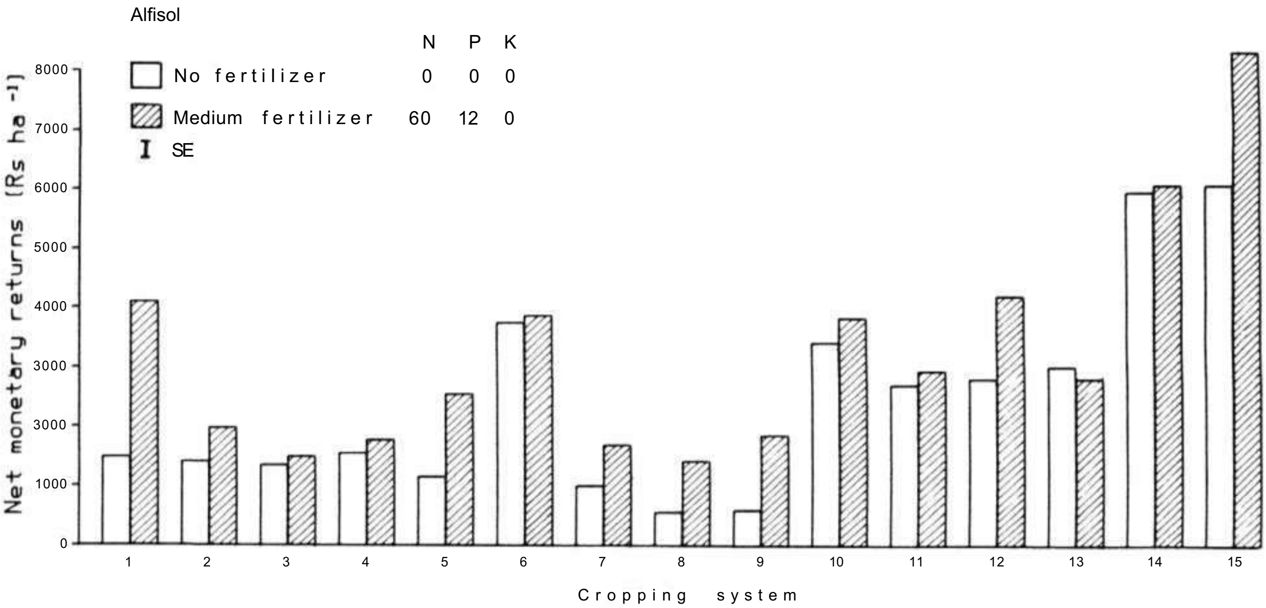
This year the yields of most crops were good because the seasonal rainfall was higher than normal and well distributed, which appears to have benefited most of the crops on this shallow soil (Fig. 21); the only exception was groundnut, which was shaded by a very good growth of the associated pigeonpea. The sorghum/pigeonpea intercrop gave the maximum net returns under both fertilizer regimes. With fertilizer inputs, the mung bean/castor intercrop also gave very high net returns; but, without fertilizer, it gave a much lower return, only half that of the sorghum/ pigeonpea intercrop, because of the very low castor yield. Without fertilizer input, the net return from the groundnut/pigeonpea intercrop was similar to that of sorghum/pigeonpea, but the return from the latter was markedly increased due to the large response by sorghum following fertilizer inputs. The millet/pigeonpea intercrop was much less remunerative than sorghum/ pigeonpea, particularly with fertilizer inputs, largely because of the lower yield of millet. Of all the intercrop systems evaluated, the mung bean/sorghum system was the least productive. The sole crop of medium-duration pigeonpea yielded 970 kg ha^{-1} without fertilizer, and 1100 kg ha^{-1} with fertilizer inputs. But the performance of early pigeonpea was much below our expectation. The combined yield from the two harvests was only 1020 kg ha^{-1} with fertilizer



Fertilizer rate	1	2	3	4	5	6	7
	Rainy-season yield (kg ha^{-1})						
	MB/	MB/	Sor/	Mil/	ON/	PP sole	EPP
Nil	230	190	1700	930	470		400
Medium	150	150	3960	2080	270		500
	Postrainy-season yield (kg ha^{-1})						
	IC Sor	IC Cas	IC PP	IC PP	IC PP		Rat
Nil	1880	600	920	750	1070	970	200
Medium	3595	1670	1030	900	1390	1110	520

(Cas = castor, EPP = early pigeonpea, GN = groundnut, Mil = pearl millet, MB = mung bean, PP = pigeonpea, Sor = sorghum, IC = intercrop, Rat = ratoon)

Figure 21. Net monetary returns (Rs ha^{-1}) and grain yields (kg ha^{-1}) from indicated cropping systems grown on an operational scale on a shallow black soil with nil and medium fertilizer inputs, ICRISAT Center, rainy and postrainy seasons 1983.



Fertilizer rate	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Rainy-season yield (kg ha^{-1})														
	Cas sole	MB	Mil-	Mil-	Sor	EPP	Sor-	MB/	Mil/	Mil/	Mil/	Sor/	SM/	GN/	GN/
Nil		360	1250	1380	1120	1030	880	210	980	660	1130	840	430	1190	1370
Medium		400	2250	2200	2280	1110	1490	240	1960	1100	1820	2050	490	1220	1440
	Postrainy-season yield (kg ha^{-1})														
		Rel Cas	Seq HG	Seq Cop	Rat	Rat	Seq Cop	1C Cas	IC Cas	1C GN	IC PP	IC PP	IC PP	IC PP	IC Cas
Nil	430	230	670	470	200	100	280	150	80	980	610	640	470	610	390
Medium	1080	520	700	530	430	140	480	420	270	1110	630	710	480	690	910

(Cas = castor, Cop = cowpea, EPP = early pigeonpea, GN = groundnut, HG = horse gram, Mil = pearl millet, MB = mung bean, PP = pigeonpea, SM = sesame, Sor = sorghum, IC = intercrop, Rat = ratoon, Rel = relay crop, Seq = sequential crop)

Figure 22. Net monetary returns (Rs ha^{1}) and grain yields (kg ha^{-1}) from indicated cropping systems grown on an operational scale on an Alfisol with nil and medium fertilizer inputs, ICRISAT Center, rainy and postrainy seasons 1983.

added and 600 kg ha^{-1} without fertilizer. Thus, on this shallow soil, the early pigeonpea did not show any advantage over the medium-duration type with fertilizer inputs and was, in fact, significantly inferior without fertilizer.

Alfisols

In 1983, we included two new intercrop systems (groundnut/castor and sesamum/pigeonpea) because our results in the two previous years showed the potential benefit of intercrop systems for Alfisols. The system of early pigeonpea (ICPL 87) and its ratoon was also included. Of the 15 systems evaluated, 9 were intercrop systems, 2 sequential, 2 ratoon, 1 relay, and 1 long-duration sole crop (castor).

The grain yield data shown in Figure 22 further confirm our earlier results that the two drought-tolerant legumes, horse gram (*Macrotyloma uniflorum)* and cowpea, could be grown sequentially after an early pearl millet crop. In

1981, castor relay-sown after mung bean appeared to be a good double crop option, but in the following two years this system performed poorly because the yield of castor was much lower than that of a full-season crop (sown at the beginning of the rains). Allowing a rainy season-sorghum crop or an early pigeonpea to ratoon was found to be an inexpensive way to get a partial second crop, albeit a low-yielding one. The temporal complementarity of intercropping systems continued to provide the basis for the best options:groundnut/castor and groundnut/pigeonpea gave the highest returns, followed by the cereal/pigeonpea and sesamum/pigeonpea systems. Yields of a sole crop of high-value castor were again very productive, as in 1982, such that only three intercrop systems gave better returns. As in the two previous years, response to added fertilizer was usually small; as a result, the most profitable systems with fertilizer inputs usually gave only a little better return than the most profitable ones without fertilizer inputs.

Entomology

Insect Monitoring

We are continuing the regular monitoring of insects using light and pheromone traps and have started to analyze the accumulated data, particularly for *Heliothis armigera,* in relation to environmental factors. One of the three ground-level light traps was resited on top of ICRISAT's 50-m high water tower. We expect this trap to catch only high-flying insects that may be migrating.

In the 1983/84 season the populations of most insects in and around ICRISAT Center appeared to be lower than in most previous years. This was evident in the catches recorded in the Vertisol watershed light traps (Table 28). We are studying the factors that influence such seasonal variations in pest populations.

Table 28. Species caught in Vertisol watershed light traps, ICRISAT Center.

	1983/84	Average previous 5 years
Heliothis armigera	2326	17955
Spodoptera litura	1569	5921
Chilo partellus	6848	10850

The increase in the numbers of *H. armigera* moths from June to September each year appears to be remarkably consistent (Fig. 23). But, after September, there is considerable year-to-year variation in the catches. We now have sufficient data to embark on an investigation of the climatic and crop factors that are likely to influence such variation.

In trap catch comparisons we found that the light traps tended to catch greater numbers of//. *armigera* moths when the nocturnal wind velocity was less than 5 km h^{-1}, but the pheromone traps caught more when wind velocities ranged from 5 to 10 km h^{-1}. It is therefore evident that the trap catches will need to be corrected for wind speeds and other factors if they are to be of real use in monitoring the populations of this pest.

Natural Enemies of the Pests

We have now completed our surveys of the parasitoids of the major pests of our target crops. Twenty-seven insects and one nematode were identified as parasites of *H. armigera* (Table 29). Of these, *Campoletis chlorideae* is the most important, for it is found in *H. armigera* larvae collected from all its host plants and in every month of the year. This parasite emerges from the 3rd instar larvae of *H. armigera* and so kills the larvae before they are large enough to cause much crop damage. Over the last 5 years we have observed that *C. chlorideae* killed 44% of the small *H. armigera* larvae on sorghum, 33% on millet, 33% on chickpea, 7% on groundnut, and 4% on pigeonpea. Another hymenopteran insect, *Trichogramma* sp is also important for it has been found in 34% of the *H. armigera* eggs collected from sorghum over the past five years. Unfortunately this parasite is extremely rare in the *H. armigera* eggs that are laid on pigeonpea and chickpea. Such parasitism differences are

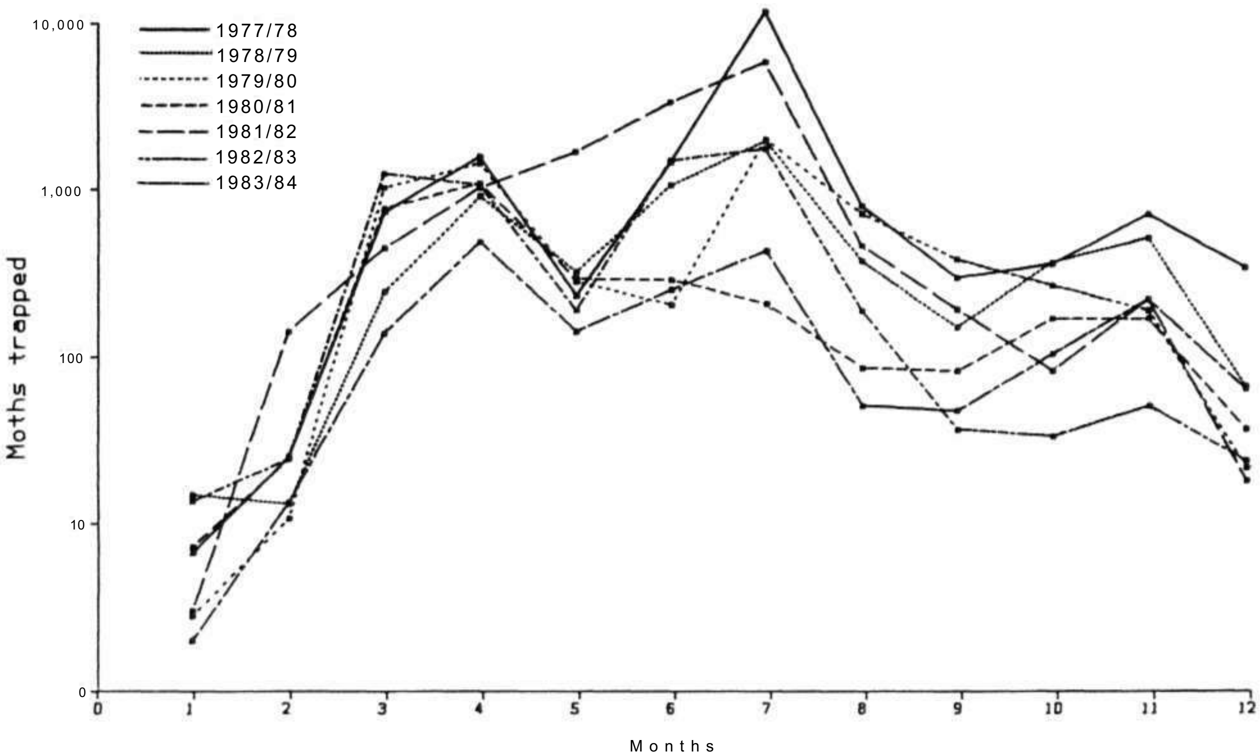


Figure 23. Monthly catches of *Heliothis armigera* in light traps (average of 3 traps), ICRISAT Center, 1977/78-1983/84.

thought to be the major reasons why *H. armigera* is such a damaging pest on pigeonpea and chickpea, but of relatively little concern on sorghum.

We have also collected information on the predators of *H. armigera.* The 21 insects that we have recorded as preying on *H. armigera* eggs and larvae are listed in Table 30. In addition there are several other animals that feed on H. *armigera* larvae, including several spiders and many birds. The quantification of predation effects on insect populations is not easy. Of the insect predators *Delta* spp appear to be the most common. *Chrysopa* spp are also found occasionally in large numbers, particularly on cotton crops.

Intercropping Studies

Insect damage was monitored in sole and intercrops. These involved pigeonpea intercropped with sorghum or maize on Vertisol and with millet or groundnut on Alfisol. There were no large, consistent differences in insect activity between the sole and intercrops for any crop. However, *H. armigera* was found to be much more damaging on crops grown on the Vertisol. For example the pod damage in pigeonpea averaged 73% on the Vertisol and 35% on the Alfisol.

Vertisol Watersheds

Water Balances Under Alternative Farming Technologies

Watersheds on Vertisols at ICRISAT Center have been managed on an operational scale since 1972, to compare the performance of contrasting management systems. We manage one watershed under the traditional system used by farmers in our area; we bare-fallow the soil during the rainy season and grow a single crop in the postrainy season on stored soil water. The improved system involves double cropping with

Table 29. Parasites that have emerged from eggs and larvae of *Heliothis armigera* collected from Andhra Pradesh, Maharashtra, and Karnataka states in India, 1974-84.

Insects	
Parasites of eggs	
Hymenoptera: *Trichogrammatidae*	
Trichogramma chilonis	*Trichogrammatoidea* sp
Trichogramma sp	*Trichogrammatoidea bactrae* sp *fumata*
Parasites of larvae[1]	
Diptera: *Tachinidae*	
Carcelia illota	*Exorista xanthaspis*
Goniophthalmus halli	*Palexorista laxa*
Sturmiopsis inferens	
Hymenoptera: *Ichneumonidae*	
Barichneumon sp	*Campoletis chlorideae*
Enicospilus shinkanus	*Eriborus argenteopilosus*
Ichneumon sp	*E. trochanteratus*
Metopius rufus	*Temelucha* sp
Xanthopimpla stemmator	
Hymenoptera: *Braconidae*	
Apanteles sp	*Bracon* sp
Chelonus sp	*Disophrys* sp
Microchelonus curvimaculatus	*Rogas* sp
Hymenoptera: *Bethylidae*	
Goniozus sp	
Nematode- *Mermithidae*	
Ovomermis albicans	

1. Some of these parasites also emerged from the pupae.

improved crops grown in both the rainy and the postrainy seasons. We now have hydrologic data from over 8 consecutive years; the long-term averages show that the improved system increases the percentage of rainfall used for crop production (from 30 to 67%), partly by reducing runoff (from 25 to 14% of rainfall). This lower runoff results in a reduced soil loss from 6400 to 1500 kg ha^{-1} a^{-1} (Table 31).

Effect of Trampling Wet Vertisols

We reported earlier (ICRISAT Annual Report 1982, pp. 264-265) that trampling beds in the Vertisol BBF system could reduce plant populations and grain yields in some postrainy-season crops. The trampling damage occurred when the surface soil was wet during harvest of the previous rainy-season crop, and the sowing of the

Table 30. Insects recorded as predators of *Heliothis armigera*, ICRISAT Center, 1977-84.

Order	Family	Species
Coleoptera	Coccinellidae	*Menochilus sexmaculatus*
Dermaptera	Carcinophoridae	*Euborellia annulipes*
		E. stall
	Labiduridae	*Nala lividipes*
Dictyoptera	Mantidae	*Humbertiella* sp
Hemiptera	Anthocoridae	*Orius maxidentex*
	Lygaeidae	*Paromius gracilis*
	Nabidae	*Tropiconabis capsiformis*
	Pentatomidae	*Cantheconidea furcellata*
	Reduviidae	*Catamiarus brevipennis*
		Ectrychotes dispar
		Rhinocoris marginatus
Hymenoptera	Eumenidae	*Delta conoideus*
		D. pyriforme
		D. companiforme esuriens
	Sphecidae	*Sphex argentatus*
	Vespidae	*Polistes olivaceus*
		Ropalidia marginata
		Vespa orientalis
		V. tropica haematodes
Neuroptera	Chrysopidae	*Chrysopa* sp

postrainy-season crop.

In the 1983/84 postrainy season we repeated this experiment because the rains continued until mid-October 1983. During the harvest of rainy-season maize grown on the BBF system, the soil was sufficiently wet (about 35% w/w) to become compacted by trampling if the harvest labor walked on the beds instead of in the furrows. We sowed chickpea and safflower, grown as sequential crops after maize. Our treatments

Table 31. Annual water balance and soil loss (kg ha^{-1}) for traditional and improved technologies in Vertisol watersheds, ICRISAT Center, 1967-77 to 1983-84.

	Water balance components				
Farming systems technology	Annual rainfall (mm)	Water used by crops (mm)	Water lost as surface runoff (mm)	Water lost as bare soil evaporation and deep percolation (mm)	Soil loss (kg ha^{-1})
Improved, double cropping on BBF	904	602 (67)[1]	130(14)	172(19)	1500
Traditional, single crop in postrainy season, and cultivation on flat	904	271 (30)	227 (25)	406 (45)	6400

1. Figures in parentheses are amounts of water used or lost expressed as % total rainfall.

Table 32. Effect of trampling beds of the BBF land-management system on stand establishment (plants ha^{-1}) and grain yield (kg ha^{-1}) of chickpea and safflower, ICRISAT Center, postrainy season 1983/84.

	Stand establishment (10^3 plants ha^{-1})		Grain yield (kg ha^{-1})	
Treatment	Chickpea	Safflower	Chickpea	Safflower
Normal beds	216	96	2330	1510
Trampled beds	148	70	1940	1110
SE	±33.9	±9.6	±33	±66

were: avoiding beds by confining traffic to the furrows (normal), and allowing traffic on the beds (trampled). Trampling significantly ($P<0.05$) reduced grain yields of both chickpea and safflower (Table 32), thus confirming our earlier observations.

Fertilizer Placement

We commenced operational testing on the effects of fertilizer placement within the seed row on a Vertisol in the 1983 rainy season (ICRISAT Annual Report 1983, p. 268), and continued these in the subsequent postrainy and rainy seasons (1983/84) using sorghum as a test crop. The 2 methods of placement compared fertilizer placed either in the seed row, or 5 cm to one side, and 5 cm below the seed row. We tested two nitrogen rates, 60 kg N ha^{-1} and 120 kg N ha^{-1}, 50% of which was applied at seeding; and four fertilizer sources, 18-46-0 (diammonium phosphate), 28-28-0 (ammonium phosphate), single superphosphate, and urea.

For all field operations we used the WTC with a four-row planter to seed and apply fertilizer. Each plot had three broadbeds, 60 m long. The fertilizer drill applied fertilizer within a 10% margin of its calibrated rate.

Results for sorghum in the 1983/84 postrainy season (Table 33) showed that fertilizer placement in the seed row increased grain yield ($P<0.10$) but did not affect plant height 35 DAE. During the 1984 rainy season, final grain yields were similar for the two placement treatments (Table 33). Thus from three seasons' data for sorghum on Vertisols, we conclude that the application of any of the above sources of fertilizer to supply upto 60 kg N ha^{-1} in the seed row does not have an adverse effect on plant establishment and growth, but may give greater yield. We are simplifying the design of a furrow opener for the planter.

Table 33. Effect of fertilizer placement on plant height (cm) during the vegetative stage, and grain yield (kg ha^{-1}) of two sorghum cultivars[1] grown on Vertisols, ICRISAT Center, postrainy season 1983/84 and rainy season 1984.

	Postrainy season 1983/84		Rainy season 1984	
Fertilizer placement	Plant height at 35 DAE (cm)	Grain yield (kg ha^{-1})	Plant height at 31 DAE (cm)	Grain yield (kg ha^{-1})
Within seed row	27	1300	15.1	4300
Below and to one side of seed row[2]	26	730	16.5	4300
SE	±2.3	±270	±0.43	±310

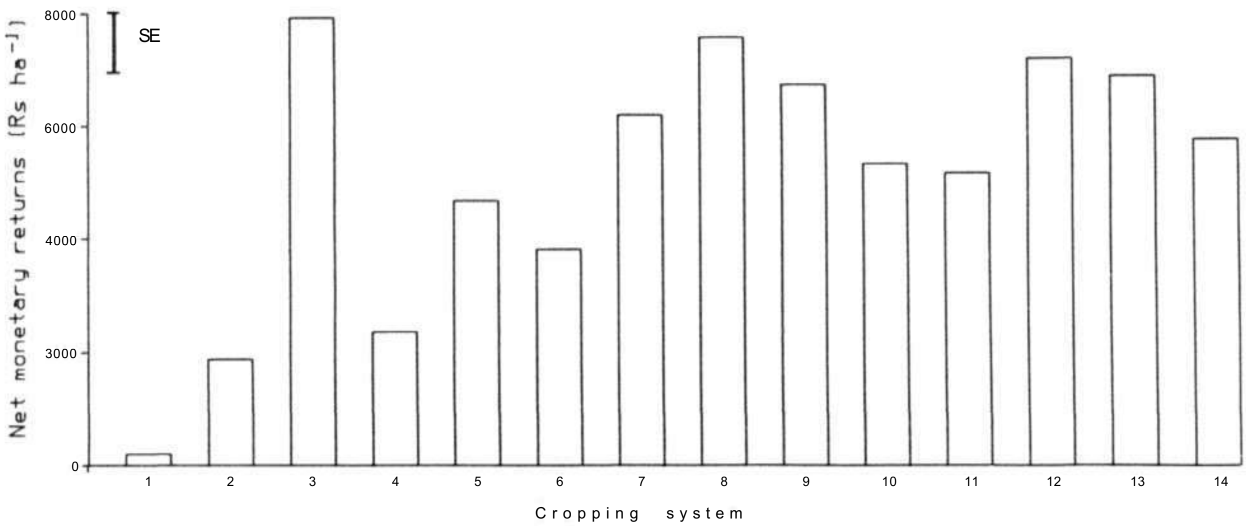
1. CSH 8 in postrainy season 1983/84 and CSH 6 in rainy season 1984.
2. Displacement 5 cm in each direction.

Evaluation at National Research Centers

Talod, Gujarat

During 1983/84, we continued an experiment initiated in 1982 in collaboration with Gujarat Agricultural University, to evaluate the performance of alternate cropping systems for light sandy soils at Talod research station in Gujarat. This experiment examined 20 cropping systems, comprising either sole crops or intercrops in a randomized block design with four replications. Basal fertilizer at 18 kg N ha^{-1} and 20 kg P ha^{-1} was applied to all crops, and a further 62 kg N ha^{-1} was topdressed on the nonlegumes. Economic plant protection was used against castor semi-looper (Achaea Janata) and pigeonpea pod borer (Heliothis armigera). Due to rainfall (1132 mm) well above the normal (700 mm) during the growing season, we encountered some disease problems in pearl millet, sorghum, and groundnut. As a result, the yields of these rainy-season crops and those of mung bean and sesamum were low, but the crops that extended into the postrainy season, such as castor and pigeonpea, produced very good yields (Fig. 24).

Net monetary returns of some of the systems tried are given in Figure 24. Although sole castor



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fertilizer rate		Rainy-season yield (kg ha^{-1})												
	Mil	GN	Cas sole	Mil/	Mil/	GN/	MB/	Gu/	SM/	Mil/	MB/	Sor/	GN/	SM/
	870	700		1020	990	610	310	1250	400	780	340	380	700	290
		Postrainy-season yield (kg ha^{-1})												
				IC GN	IC Gu	IC Cas	IC Cas	IC Cas	IC Cas	IC PP	IC PP	IC PP	IC PP	IC PP
			1540	630	1800	530	1110	980	940	1400	1340	2060	1430	1270

(Cas = castor, GN = groundnut, Gu = guar, Mil = pearl millet, MB = mung bean, PP = pigeonpea, SM = sesame, Sor = sorghum, IC = intercrop)

Figure 24. Net monetary returns (Rs ha^{-1}) and grain yields (kg ha^{-1}) from indicated cropping systems grown on an Entisol, Talod, Gujarat, rainy and postrainy seasons 1983.

gave the highest net returns, there were several intercrop systems, such as guar or cluster bean (*Cyanopsis tetragonoloba)/* castor, sesamum / castor, sorghum/pigeonpea, and groundnut/ pigeonpea, that all gave comparably high returns. Out of the 20 sole and intercrops examined, 10 gave net returns over 4000 Rs ha"[1]. Six of the 10 intercropping systems had yield advantages of more than 60% over the sole crops; intercropping therefore enabled one and a half crops to be grown instead of one. These results further emphasize the importance of intercropping systems in increasing the cropping intensity on light soils by combining short-duration crops such as pearl millet, sorghum, groundnut, or sesamum with long-duration crops such as pigeonpea or castor.

Transfer of Technology-Deep Vertisols

On-farm evaluations of our improved farming systems for deep Vertisols began at one site in 1981, and have since expanded. In 1984 tests were conducted at 28 locations involving 1406 farmers on 2122 ha. These evaluations away from ICRISAT Center are conducted with various combinations of the component subsystems that comprise the technology. But the underlying principle remains the same: two crops are grown where only one grew before, and each of the two improved crops is more productive than the single traditional crop.

The major components directly contributing to improved productivity are improved cropping systems (often using improved cultivars), and nutrient inputs. Other optional components whose full contribution can be difficult to evaluate, include seedbed preparation during the noncropping dry season; dryseeding crops just before the onset of the rainy season; use of BBFs to improve drainage and thus reduce waterlogging, while minimizing soil erosion; sowing crops in rows to allow passage of wheeled implements that can facilitate side-dressings of nitrogenous fertilizer; intercultivation to control weeds; and the use of insecticides. Many of these components are optional; and for many of the options, several variations exist—to be applied in various ways at various locations.

Although the target area for the improved system is fairly well defined and homogeneous, i.e., deep Vertisols under assured rainfall (about 800 mm or more each year), we know that some components of the system will vary in importance across this area, and that modifications to these components may be desirable.

Stages in the transfer of this technology involve several approaches.

- ICRISAT staff test major options of the system in farmers' fields at selected benchmark sites.
- We conduct detailed replicated experiments adjacent to these benchmark locations to determine modifications in various components of the system.
- National programs then evaluate the technology at a large number of locations.

Benchmark Locations

Our three major locations outside ICRISAT Center are: Taddanpally, 40 km from ICRISAT Center but with almost identical soil and rainfall; Begumganj, 1000 km north northwest in Madhya Pradesh, where the annual rainfall is considerably higher (1000 mm), and where the postrainy-season cereal was traditionally wheat not sorghum; and Farhatabad in Karnataka, 200 km west and just outside the delineated area of assured rainfall, therefore providing a test for the technology's flexibility.

In earlier years we obtained very similar results at Taddanpally to those from operational research at ICRISAT Center (ICRISAT Annual Reports 1981, pp. 294-296; 1983, pp.279-281). We have now discontinued active participation at this site, so that we can observe the options chosen by farmers, without any guidance from ICRISAT staff.

Our second benchmark site, Begumganj, gave very encouraging results (Table 34), especially when compared to those from 1982/83.

Table 34. Economic evaluation of the improved watershed-based technology options on deep Vertisols in the Begumganj watershed, Madhya Pradesh, India, 1983/84.

Cropping systems	Land and water management	Proportions grown	Gross returns (Rs ha^{-1})[1]	Operational costs (Rs ha^{-1})	Gross profits (Rs ha^{-1})	Yields (kg ha^{-1}) Crops	Grain	Fodder	No. of plots
Improved cropping systems, improved land management[2]									
Soybean/pigeonpea	BBF	60	5036	2310	2726	Soybean	1013	1000	8
						Pigeonpea	478	1000	
Soybean/pigeonpea	Flat on grade	5	4507	2172	2335	Soybean	830	800	1
						Pigeonpea	476	1500	
Soybean-wheat	BBF, Flat on grade	22	5378	2261	3117	Soybean	1078	1100	1
						Wheat	969	900	
Soybean-chickpea	Flat on grade	13	4877	2532	2345	Soybean	850	1000	1
						Chickpea	709		
Weighted averages			5064	2321	2743				
Improved cropping systems, traditional land management[2]									
Soybean/pigeonpea	Traditional	20	4584	1497	3087	Soybean	654	600	3
						Pigeonpea	679	1000	
Soybean-wheat	Traditional	50	3888	1488	2400	Soybean	739	700	3
						Wheat	773	700	
Soybean-chickpea	Traditional	30	4690	1781	2909	Soybean	550	500	1
						Chickpea	980		
Weighted averages			4268	1578	2800				
Traditional cropping systems and land management[2]									
Fallow-wheat	Traditional	60	1315	914	401	Wheat	664	600	3
Fallow-chickpea	Traditional	40	1665	937	728	Chickpea	555		3
Weighted averages			1455	923	532				13

1. Prices of produce used for calculating gross returns are:

Grain	*Rs/100kg*	*Fodder*	*Rs/100kg*
Soybean	300	Soybean	20
Pigeonpea	350	Pigeonpea	12.5
Wheat	180	Wheat	20
Chickpea	300		

2. Data refer to 14.7 ha of watershed under improved land management, and 9.2 ha under traditional land management.

Improved cropping systems based on double-cropping gave gross profits of about Rs 2700, or almost five times more than the Rs 580 from the traditional single crop of wheat or chickpea in the postrainy season. In 1984, there was little measured effect of the improved land-management system on economic returns, but some benefits of the improved land-management options that are difficult to quantify. Timeliness is one example: the drainage of the land can, in some years, determine whether a crop is established; weeding can be satisfactorily accomplished; or fertilizer applied. Costs of production were higher than expected in both 1982 and 1983, because of the limited success of dry seeding, and a resultant need for gap filling and additional cultivation for weed control.

Our results from Farhatabad in 1984 were disappointing, but in line with our original concept, this site lies outside the area demarcated as having assured rainfall in the rainy season. In 1983, the rainy season started late so that crops were dry-seeded too far ahead of the rains, and failed. Also, the rainy season did not last long enough for double-cropping, but we did get two positive results. The BBF system appears to assist infiltration of rainfall into the soil. And, after preliminary insect-control trials using the CDA, suitably modified for mounting on a WTC or bullock cart, it was adopted at once by farmers, to the extent that the original was copied by them and manufactured in the village. In an area where sole pigeonpea is a common crop, control of *Heliothis armigera* is crucial to its success. Farmers are aware of this need, but had been applying too much insecticide. By developing simple rules to guide them in a 'spray/ no-spray decision', we have shown them how to reduce the number of sprays from 6-7 to 2-3 per season, with consequent substantial savings.

National Programs

Encouraged by the 1982 results at our Farhatabad site, the Department of Agriculture in Karnataka tested our technology in the districts of Belgaum, Bellary, Bidar, Dharwad, Gulbarga, and Raichur during 1983. The total area under the improved system was 227 ha, and the Department has prepared plans for further extension during 1984 to a surveyed area of 1354 ha.

Implementation of the technology has been highly successful primarily due to the versatility employed in its application. Although many of the sites used to test the improved system lie outside the delineated area of assured rainfall, the farmers and the Department of Agriculture exercise considerable selection and modification of the options present in the technology. For example, some rainy-season fallowing will continue in this area solely to conserve water for a postrainy-season sorghum crop where rainfall is marginal. However, the BBF land-management system seems to be well received by the farmers because it assists water infiltration into the soil in the drier locations. Modifications include increasing the width of the broadbeds depending on soil texture and annual rainfall.

In Maharashtra the State Department of Agriculture selected 5065 watersheds for future watershed-based dryland agricultural development, and initiated development on 1198 ha during 1983. The improved technology gave good yield increases, e.g., 6-200% for cotton, 10-124% for sorghum, 11-100% for mung bean, 21-200% for pigeonpea, and 28-425% for pearl millet. The variability in these yields was mainly because some locations had insufficient or undependable rainfall. The Department of Agriculture intends to proceed with rainfall-probability analyses for the various locations to help formulate its plans for testing our technology over 1900 ha in the 1984/85 season.

Adaptive Component Research

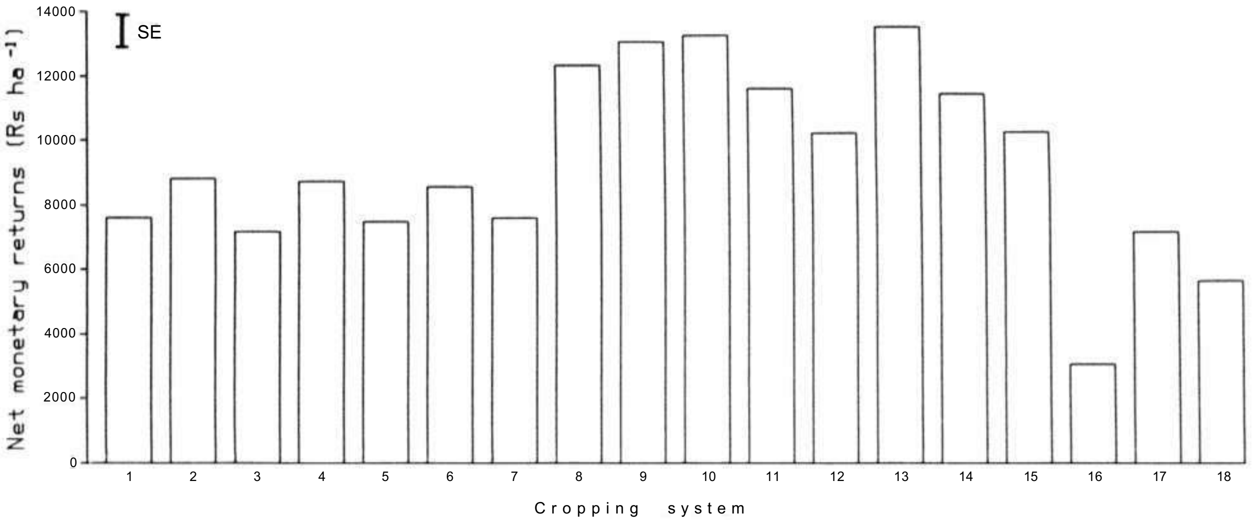
Crop Combinations

Each year, we have tested a large number of cropping systems' options in replicated experiments on a state seed farm, adjacent to the watersheds at Farhatabad and Begumganj, that encompass the farmers' operational testing of a smaller number of crop combinations. This year at Begumganj we achieved much higher productivity and economic returns from systems based on rainy-season cereals than in the previous year, mainly because the early rainfall was better distributed, thus allowing weeding and a second application of nitrogenous fertilizer (Fig. 25).

Our parallel experiment at Kotnur, a site near the Farhatabad watershed, failed because of the delayed onset of the rainy season.

Cropping-Entomology Studies

We continued on-farm monitoring of insects and



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rainy-season yield (kg ha^{-1})																	
SB1- 1806	SB2- 2192	SB2H- 1619	SB1- 1956	SB1- 1800	SB2- 2008	SBI/ 1619	SBI/ 161 IC MZ1- 7201	SB2/ 250 IC MZ2- 7492	MZ1/ 7983	MZ1- 7797	MZ2- 6576	MZ1- 8044	MZ2- 7417	MZ2- 6434	Fal-	PP 1783	Sor/ 2667
Postrainy season yield (kg ha^{-1})																	
Seq Wht 2400	Seq Wht 2422	Seq Wht 2561	Seq CP 1717	Seq SF 1072	Seq SF 1192	IC PP 1306	Seq CP 1728	Seq CP 1744	IC PP 1367	Seq Wht 2039	Seq Wht 2144	Seq CP 1806	Seq CP 1378	Seq SF 1039	Wht 2275	Rat PP 790	IC PP 1133

(CP = chickpea, MZI = late maize D101, MZ2 = early maize Ganga 5, PP = pigeonpea, SF = safflower, SBI = late soybean JS72-44, SB2 = early soybean JS-2, Sor = sorghum, Wht = wheat, Fal = fallow, H = herbicide, IC = intercrop, Seq = sequential crop)

Figure 25. Net monetary returns (Rs ha^{-1}) and grain yields (kg ha^{-1}) from indicated cropping systems grown under the broadbed-and-furrow (BBF) land management system on a deep Vertisol. Begumganj Seed Farm, Madhya Pradesh, rainy and postrainy seasons 1983/84.

their natural enemies and training farmers in pesticide-application techniques at Narayankhed, Farhatabad, and Begumganj.

Pests and their Parasites

Insect damage on the rainy-season crops was generally low. Less than 2% of the sorghum plants had deadhearts caused by shoot fly *(Atherigona* spp) and stem borer *(Chilopartellus).* On soybean the girdle beatle *(Oberia brevis)* caused relatively less damage this year. *Heliothis armigera* was of little importance on sorghum, where the peak population recorded was 7.3 larvae/100 heads, and on maize where there were 6.0 larvae/100 cobs.

On pigeonpea the peak *H. armigera* infestations during October-November averaged 18 (±5.4) eggs and 4.0 (±0.4) larvae plant^{-1} at Narayankhed, and 17 (±7.8) eggs and 4.2 (±0.73)

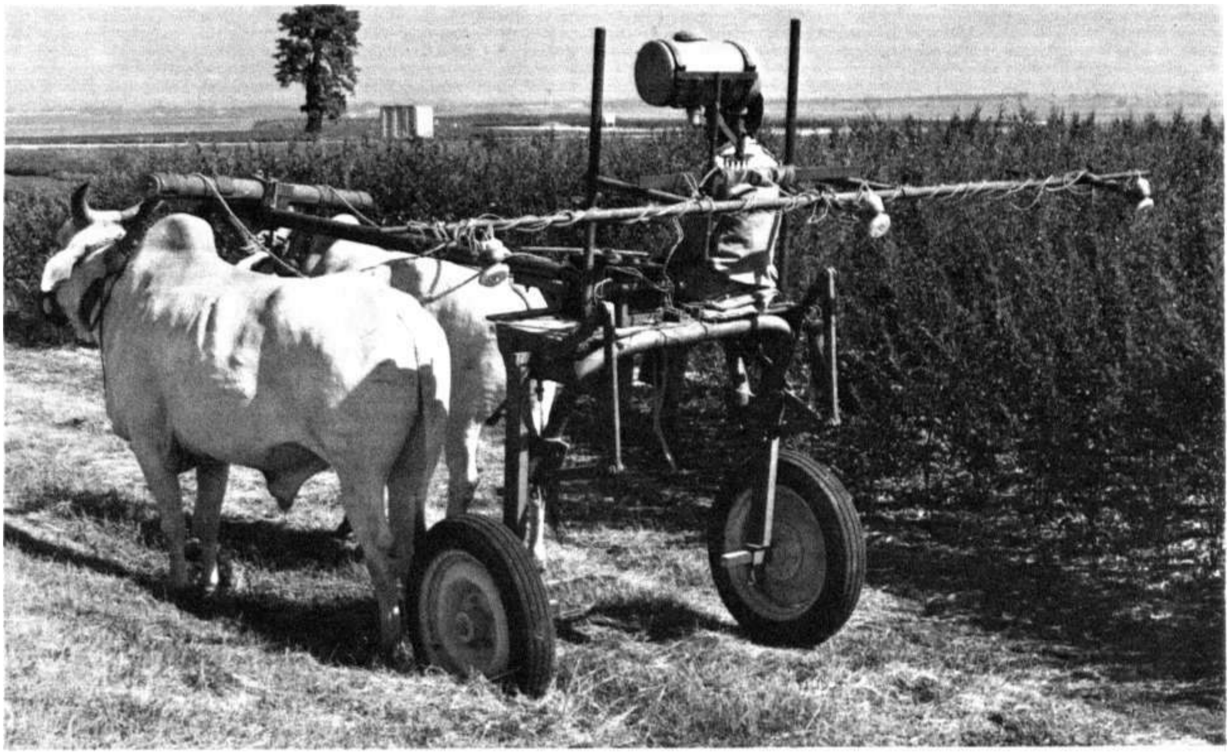


Figure 26. Three CDA sprayers mounted on a Tropicultor adjusted for operation in tall crops (above), and in use for spraying insecticides on pigeonpeas (below), Vertisol watershed, Farhatabad, Karnataka, postrainy season 1984/85.

larvae $plant^{-1}$ at Farhatabad. At Begumganj, where flowering started in December, we found only 0.5 (±0.17) eggs and 1.1 (±0.10) larvae $plant^{-1}$. At Begumganj the *H. armigera* population on the chickpea crop was relatively higher than at other on-farm locations.

Campoletis chlorideae was the most common parasite of *H. armigera* at all locations, being found in 63% of the small larvae (1st-3rd instar) collected from sorghum, and in 42% of larvae collected from maize. This parasite was also common in larvae collected from chickpea at Begumganj, and from pigeonpea at Narayankhed and Farhatabad. Larvae collected from pigeonpea at Begumganj were not parasitized by *C. chloridae* but by *Eriborus argenteopilosa.* The most common parasites emerging from the large *H. armigera* larvae that we collected were the dipteran species *Carelia illota* and *Gorioph-thalmes halli.* However, larval parasitism by these flies did not exceed 5%.

Plant Protection

The deep Vertisol technology-verification trials were protected by insecticides where pest counts indicated that their use was necessary. Demonstrations of the CDA in use were highly effective, and consequently some farmers in Farhatabad purchased CDA equipment to replace their conventional sprayers. A video film on the 'Control of pigeonpea pod borer', produced by ICRISAT, has proved popular in training sessions for extension workers and farmers.

We mounted a spray boom incorporating 3 to 5 CDA units on a Tropicultor (Fig. 26) and found it convenient and effective for spraying pigeonpea at ICRISAT Center. We will test this assembly in farmers' fields in the coming season.

Training Courses

We hold training courses at ICRISAT Center so that officers of State Departments of Agriculture can become more familiar with various aspects of our technology before they plan and execute projects in the appropriate areas of their states. In 1984 we spent 36 days on training courses, attended by a total of 206 participants. The courses were designed for staff from the Departments of Agriculture of Madhya Pradesh, Tamil Nadu, Andhra Pradesh, and Karnataka. The courses lasted from 2 to 9 days, and were principally of two types: supervisory, for the senior officers of the State Departments, and practical, for agricultural officers working in the field.

Routine Soils Laboratory

During 1984 we completed 61500 analyses in the routine analytical laboratory, about 20% more than the average for the past 5 years.

We had previously tested simplified methods to determine the potassium content of plant tissue. These involved potassium determination by either an ammonium acetate/magnesium acetate mixture, or by dilute hydrochloric acid. Both are much simpler than the conventional tri-acid digestion method, and should theoretically be equally effective because potassium is not a constituent of the plant's structural components. Early evaluations were made on dried plant tissue, but we have since used the method on grain samples because the different texture of these may alter extra availability of potassium. Table 35 shows that the simple and rapid HC1-extraction method is also quite adequate for grain samples; because this method is much simpler than the others, we use it whenever samples do not require digestion.

International Cooperation

Resource Evaluation in Africa

Agrometeorology of Burkina Faso

In cooperation with the national Meteorological Services of Burkina Faso, we assembled and analyzed data on long-term daily rainfall, temperature, potential evapotranspiration, and water balance for 130 locations in Burkina Faso.

We have computed the annual, seasonal, monthly, and decadal (10-day period) rainfall

Table 35. Precision of the HCl-extraction and tri-acid digestion methods for determination of K (%) in grain samples.

		K content (%)[1]		
Crop	Method	Range	Mean	SE
Chickpea	HC1 extraction	0.94 - 0.98	0.96	±0.013
	Tri-acid	0.94 - 0.97	0.96	±0.016
Pigeonpea	HC1 extraction	1.65 - 1.68	1.66	±0.011
	Tri-acid	1.61 - 1.65	1.63	±0.017
Sorghum	HC1 extraction	0.50 - 0.53	0.52	±0.013
	Tri-acid	0.50 - 0.55	0.53	±0.022
Pearl millet	HO extraction	0.65 - 0.67	0.66	±0.006
	Tri-acid	0.63 - 0.64	0.63	±0.005

1. Based on five independent analyses.

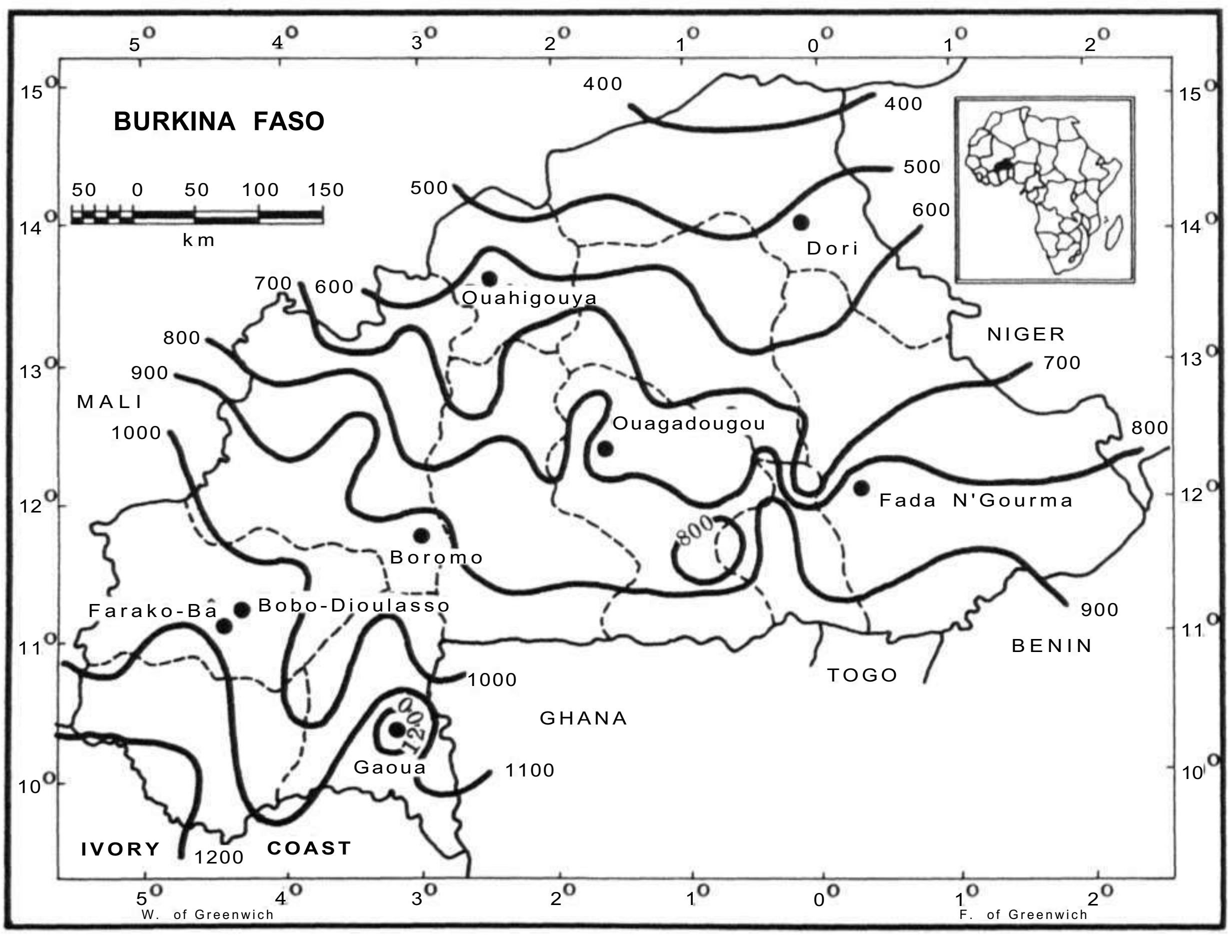


Figure 27. Mean annual rainfall (mm) in Burkina Faso.

totals for each location and prepared maps of rainfall variability across Burkina Faso. The frequency distribution of the mean annual rainfall at these locations (Table 36) shows that about 55% of the stations fall in the 800-1200 mm frequency class. Average rainfall for these locations is 831 mm, with a CV of 23%.

The improved delineation of the geographic distribution of mean annual rainfall in Burkina Faso (Fig. 27) allows a better delineation and subdivision of the climatic zones:

1. Sahelian Zone, with less than 650 mm rainfall of high variability in distribution and a short rainy season; extends north of the 14°N latitude.
2. Northern Sudanian Zone, between the 650 mm and 1000 mm isohyets and with a rainy season shorter than six months; extends between 11°30'and 14°N latitude.
3. Southern Sudanian Zone, with greater than 1000 mm mean annual rainfall received over about half of the year, extends south of the 11°30'N latitude.

We computed the probabilities of receiving 10, 20, 30, 40, and 50 mm rainfall in a given decadal period, using Markov chain probabilities. Twenty-five maps have been prepared using data

Table 36. Frequency distribution of total annual rainfall (mm) for 130 stations in Burkina Faso[1].

Annual rainfall (mm)	Stations	% of total rainfall
400 - 500	5	3.8
500 - 600	13	10.0
600 - 700	17	13.1
700 - 800	22	16.9
800 - 900	23	17.7
900 - 1000	25	19.3
1000 - 1100	13	10.0
1100 - 1200	10	7.7
1200 - 1300	2	1.5
Total	130	100.0

1. Mean annual rainfall = 831 mm; SD = 189 mm; CV = 23 (%).

from the prerainy, rainy, and postrainy seasons over five decades to show the regional patterns in rainfall probabilities. We identified the following regional patterns from the calculated probabilities:

- In mid-May, the probabilities of receiving even 10 mm of rainfall are low in the Sahelian Zone, whilst in the southern Sudanian Zone the probabilities exceed 70% (Fig. 28). By late June the probabilities increase to 90% in the northern Sudanian Zone, but do not reach this level in the Sahelian zone till late July.
- The probabilities of receiving 30 mm or more rainfall during July and August when crops reach active vegetative growth are high in the southern Sudanian Zone, but low in the Sahelian Zone, which is in agreement with the known risk for high-value crops or crops with high water requirement.
- Our calculations of expected amounts of rainfall at specified probabilities of 25, 50, 75, and 90% show that only locations in the southern Sudanian zone have a high potential for assured cropping. North of the thirteenth parallel the expected rainfall is low.

In the southern Sudanian Zone during the dry season, the mean maximum temperatures vary between 33 and 37°C and the mean minimum temperatures between 17 and 25°C. During the rainy season the mean maximum temperatures range between 29-34°C and the mean minimum temperatures are around 21°C. In the northern Sudanian Zone, the mean maximum air temperatures during the rainy season are about 30-36° C while the mean minimum temperatures vary between 20-25°C. In the Sahelian Zone, the diurnal variation in temperature is markedly higher (15-20°C) during the dry season than during the rainy season (8-10°C).

Using the precipitation and potential evapotranspiration data for eight locations, we computed the decadal available soil-moisture storage and the length of the growing season using the Commonwealth Scientific and Industrial Research Organization (CSIRO) water-

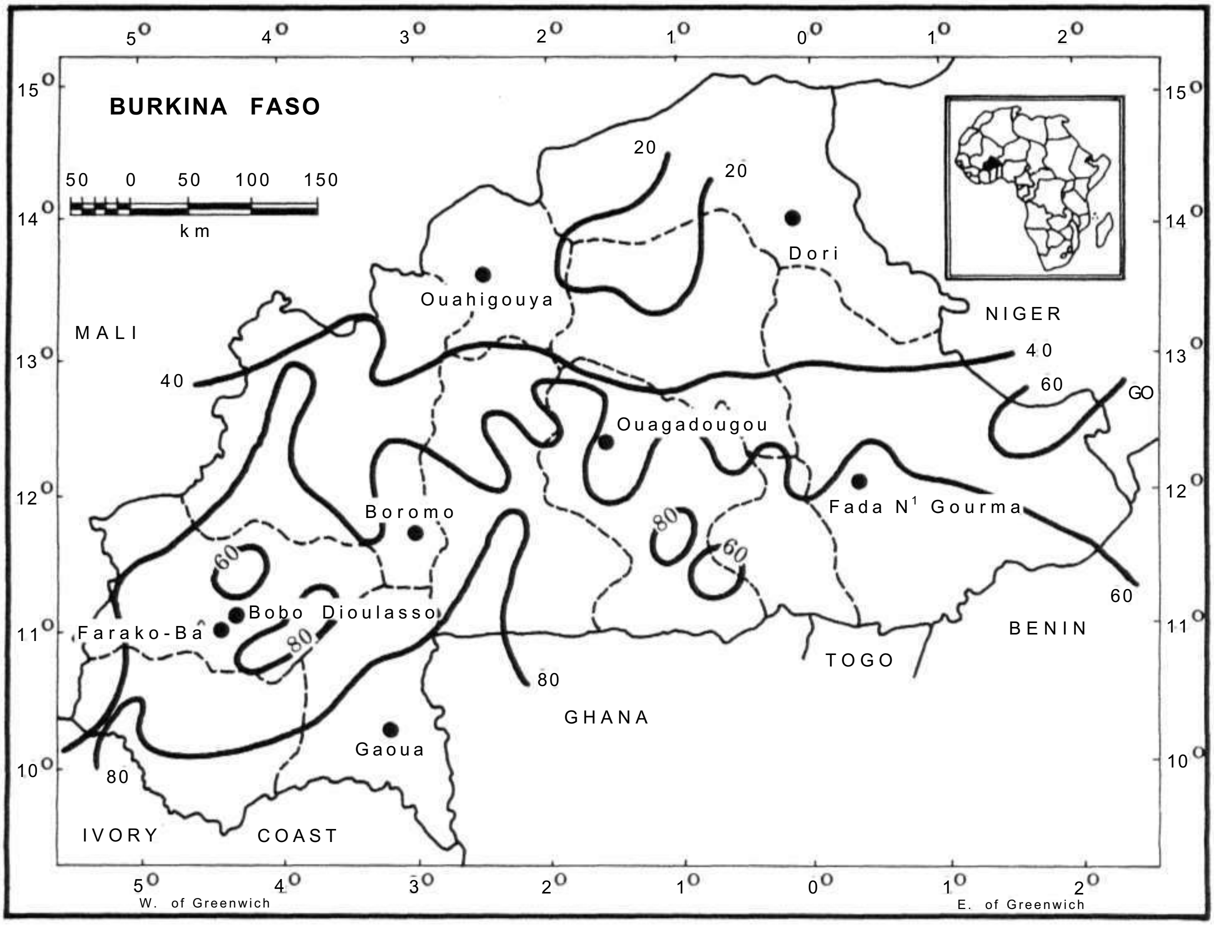


Figure 28. Probability (%) of receiving 10 mm or more rainfall from 11 to 20 May in Burkina Faso.

balance model. The *length* of the growing season varies from 90 days at Dori (Table 37) to 210 days at Gaoua, with 200 mm water-holding capacity. At Dori and Ouahigouya, soil-moisture availability will support only a short-duration crop of millet.

Analysis of Rainfall in Malawi

ICRISAT has recently commenced an intensive groundnut improvement program in Malawi in cooperation with the Southern African Development Coordination Conference (SADCC) countries. To complement this work, a detailed agroclimatic description of Malawi is being made in cooperation with the Malawi Meteorological Services. We compiled rainfall data for 140 locations, and commenced computer analyses of annual, monthly, and seasonal precipitation. The data for five selected stations located in the groundnut-growing belt (Fig. 29) illustrate the variation across the country (Table 38). The average total annual rainfall at these five locations varies from 800 to 1200 mm and most (> 90%) of the rainfall is concentrated into a well-defined rainy season extending from November to March. The months May to September receive little rainfall.

Our analyses to determine the amounts of rainfall expected at different probabilities involve fitting a Gamma-distribution curve to the data. We use the expected amount of rainfall at 75% probability as our criterion of depend-

Table 37. Annual rainfall in 1984 and predicted length of the growing season (days) for soils with water-holding capacities of 100 and 200 mm for eight stations in Burkina Faso.

Station	Annual rainfall (mm)	Soil water-holding capacity (mm)	Length of growing season (days)[1]
Gaoua	1240	100	200
		200	210
Farako-Ba	1080	100	170
		200	180
Bobo-Dioulasso	1076	100	160
		200	180
Boromo	960	100	160
		200	170
Fada N'Gourma	863	100	150
		200	150
Ouagadougou	774	100	150
		200	150
Ouahigouya	689	100	110
		200	130
Dori	505	100	90
		200	90

1. Rounded off to the nearest 10 days.

Table 38. Mean monthly and annual rainfall (mm) at five selected locations in the groundnut-growing belt, Malawi[1].

	Location				
Month	Bvumbwe	Salima	Mchinji Boma	Chitedze	Nsanje
January	259	298	239	229	158
February	217	234	217	182	145
March	183	248	181	132	132
April	117	69	68	47	45
May	20	12	9	8	12
June	23	3	2	2	16
July	17	1	1	1	13
August	12	0	2	1	9
September	7	0	2	2	8
October	24	5	19	5	17
November	101	30	107	77	84
December	221	212	207	194	150
Annual	1201	1132	1054	880	789

1. Based on 58, 30, 26, 41, and 33 years of rainfall data for Mchinji Boma, Chitedze, Salima, Nsanje, and Bvumbwe respectively.

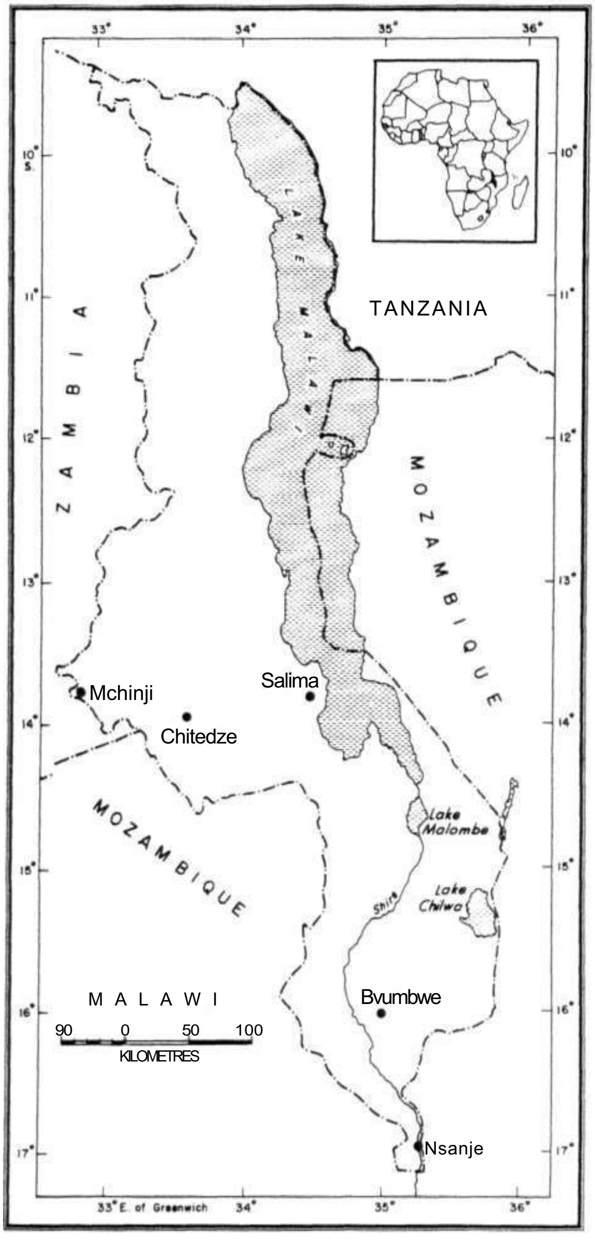


Figure 29. Location of five stations selected for rainfall-data analysis in Malawi.

able rainfall. About 80% of the mean annual rainfall is dependable. Rainfall at all locations is fairly dependable during the growing season, which exceeds 140 days, and is 184 days at Bvumbwe and Mchinji Boma. However, less than 20 mm rain can be expected during the postrainy season. Crops maturing in this period mainly depend on soil storage for their moisture (Table 39).

Component Research: ISC

Agroclimatology: Multilocational Water-Balance Studies in Niger

In cooperation with the National Meteorological Services of Niger, we initiated water-balance studies at three locations in Niger: Sadore (ISC), Dosso, and Gaya. We grew pearl millet at Sadore and Dosso; at Gaya, where the mean annual rainfall is 839 mm, the crops included sole crops of pearl millet, sorghum, maize, and groundnut, and intercrops of millet/groundnut and millet/cowpea. We applied N, P, and K at 45, 20, and 25 kg ha^{-1} or no fertilizer; bare soil was an additional treatment. We monitored soil moisture at 10-15 day intervals throughout the growing season, and measured dry matter and LAI at regular intervals.

At all three locations, rainfall in 1984 was considerably lower than the normal (Table 40). At Sadore, the millet crop established well with moderate rainfall at the end of May and early June, but it suffered severely from drought stress due to low rainfall in August and September. At Dosso, July and August rainfall was well below normal, but good rain in September helped the millet crop. At Gaya, maize and sorghum failed because of insufficient rain early in the season; millet in the sole crop as well as intercrop was poor, but late rains in September alleviated the drought stress.

Dry-matter distribution in different plant components at Sadore (Fig. 30) shows the good establishment of millet in early June contributed to vigorous early growth which continued till mid-August (70 DAE). Subsequent lack of rain led to loss of dry matter, especially the stem component. Fertilizer treatments significantly increased dry-matter accumulation.

At Dosso, lower rainfall in July and August (Table 40) led to slower early growth (Fig. 31) than at Sadore. However, above-normal rainfall

Table 39. Minimum amounts of seasonal rainfall for each of four different probabilities for five selected locations in Malawi[1].

Location	Length of growing season[2] (days)	Season[3]	Dates	Minimum amount of rainfall (mm) expected				Mean rainfall (mm)
				Probability (%)				
				90	75	25	10	
Bvumbwe	184	Dry	7 May- 7 Oct	28	45	104	142	79
		Prerainy	8 Oct- 4 Nov	4	9	37	58	26
		Rainy	5 Nov-22 Apr	665	821	1252	1488	1054
		Postrainy	23 Apr- 6 May	0	4	58	123	44
Mchinji Boma	184	Dry	7 May-21 Oct	2	5	26	44	18
		Prerainy	22 Oct- 4 Nov	1	3	23	42	16
		Rainy	5 Nov-15 Apr	707	827	1142	1307	994
		Postrainy	16 Apr- 6 May	2	6	39	69	27
Chitedze	163	Dry	30 Apr-28 Oct	3	6	26	43	18
		Prerainy	29 Oct-18 Nov	3	10	46	77	32
		Rainy	19 Nov- 1 Apr	477	599	942	1132	785
		Postrainy	2 Apr-29 Apr	8	17	63	98	45
Nsanje	156	Dry	30 Apr-21 Oct	29	43	89	118	69
		Prerainy	22 Oct-25 Nov	8	22	106	176	76
		Rainy	26 Nov- 8 Apr	393	483	733	869	618
		Postrainy	9 Apr-29 Apr	3	9	39	63	27
Salima	142	Dry	23 Apr-18 Nov	3	10	59	102	42
		Prerainy	19 Nov- 2 Dec	1	5	37	67	26
		Rainy	3 Dec- 1 Apr	574	742	1226	1499	1007
		Postrainy	2 Apr-22 Apr	1	7	78	158	58

1. Based on 33, 58, 30, 26, and 41 years of rainfall data for Bvumbwe, Mchinji Boma, Chitedze, Nsanje, and Salima.
2. Growing season = Rainy plus postrainy seasons.
3. Seasons are considered as dry, prerainy, rainy, and postrainy when the probability of getting at least 10 mm of rainfall is 0 to 15%, 15 to 45%, 45 to 100%, and 15 to 45%.

Table 40. Actual monthly rainfall (mm), compared to normal at three locations, Niger, 1984.

Month	ISC, Sadore		Dosso		Gaya	
	1984	Normal	1984	Normal	1984	Normal
May	44	35	46	39	45	65
Jun	42	77	105	77	52	121
Jul	9!	143	50	149	99	190
Aug	57	198	58	220	93	257
Sept	26	89	123	107	140	156
Oct	0	17	0	12	21	20
Rainy season	260	570	380	615	515	831

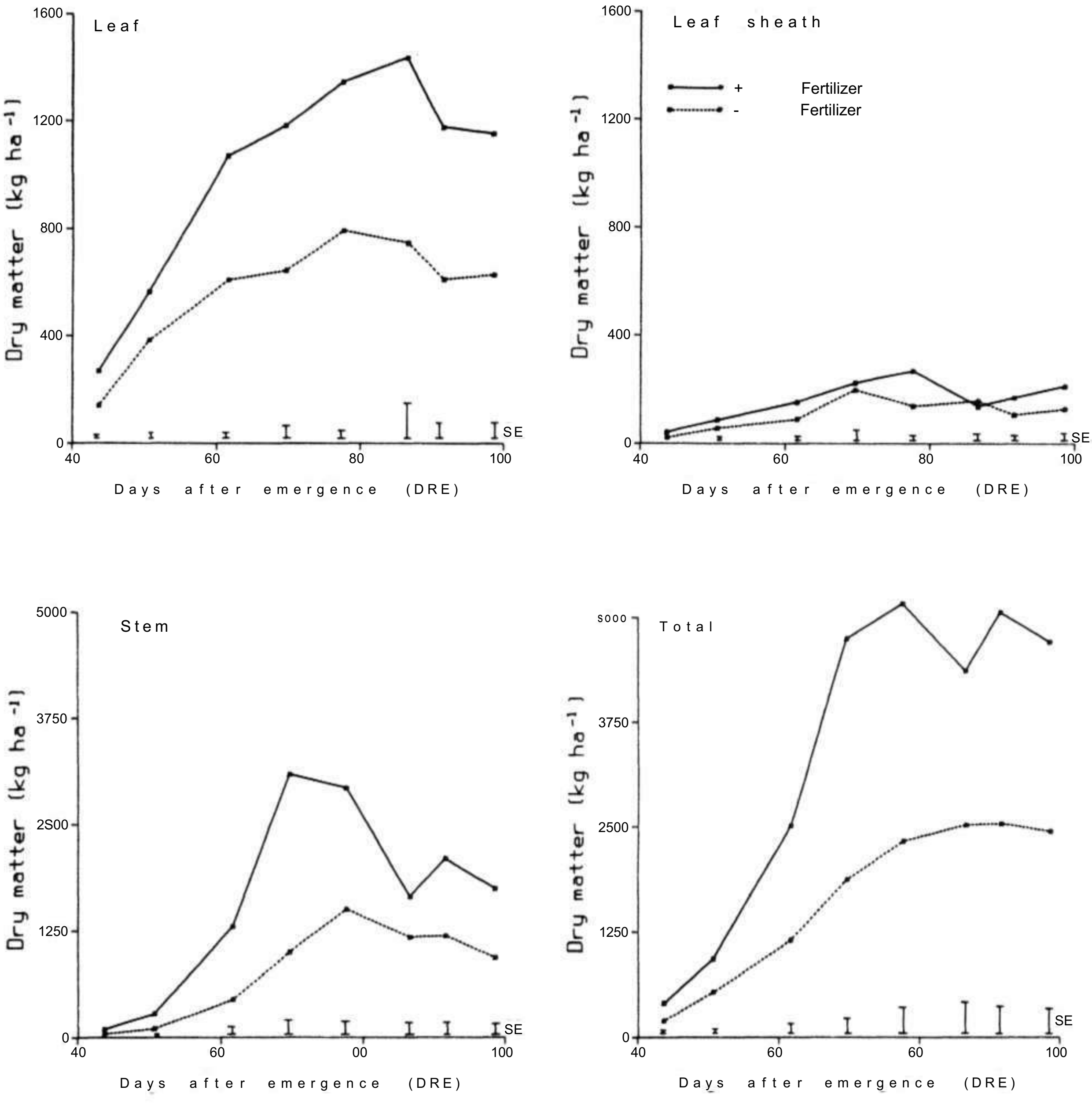


Figure 30. Dry-matter distribution in different plant components of millet cv CIVT, ISC, Niger, rainy season 1984.

in September enhanced crop growth. At Sadore, fertilizer application increased pearl millet grain yield, but did not significantly increase water use or WUE (Table 41). At Dosso, fertilizer application significantly reduced water use, and the loss of water from the bare soil was similar to the water use by the millet that did not receive fertilizer. Apparently, the good plant canopy of the millet crop helped to reduce water loss by evaporation from the soil. Because fertilizer increased millet yield, the WUE of the millet with fertilizer was 2-3 times greater than that without fertilizer.

Table 41. Pearl millet (CIVT) water use (WU), grain yield (Y), and water-use efficiency (WUE) with and without fertilizer application compared to water loss from bare soil, Sadore and Dosso, rainy season 1984.

	Sadore			Dosso		
Treatment	WU (mm)	Y (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	WU (mm)	Y (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})
Fertilizer	165	410	2.48	247	1120	4.54
No Fertilizer	163	290	1.78	270	480	1.78
Bare soil	232	-	-	275	-	-
SF	±4.1	±4.3	±0.65	±4.8	±12	±0.07
CV (%)	4	30	18	4	4	5

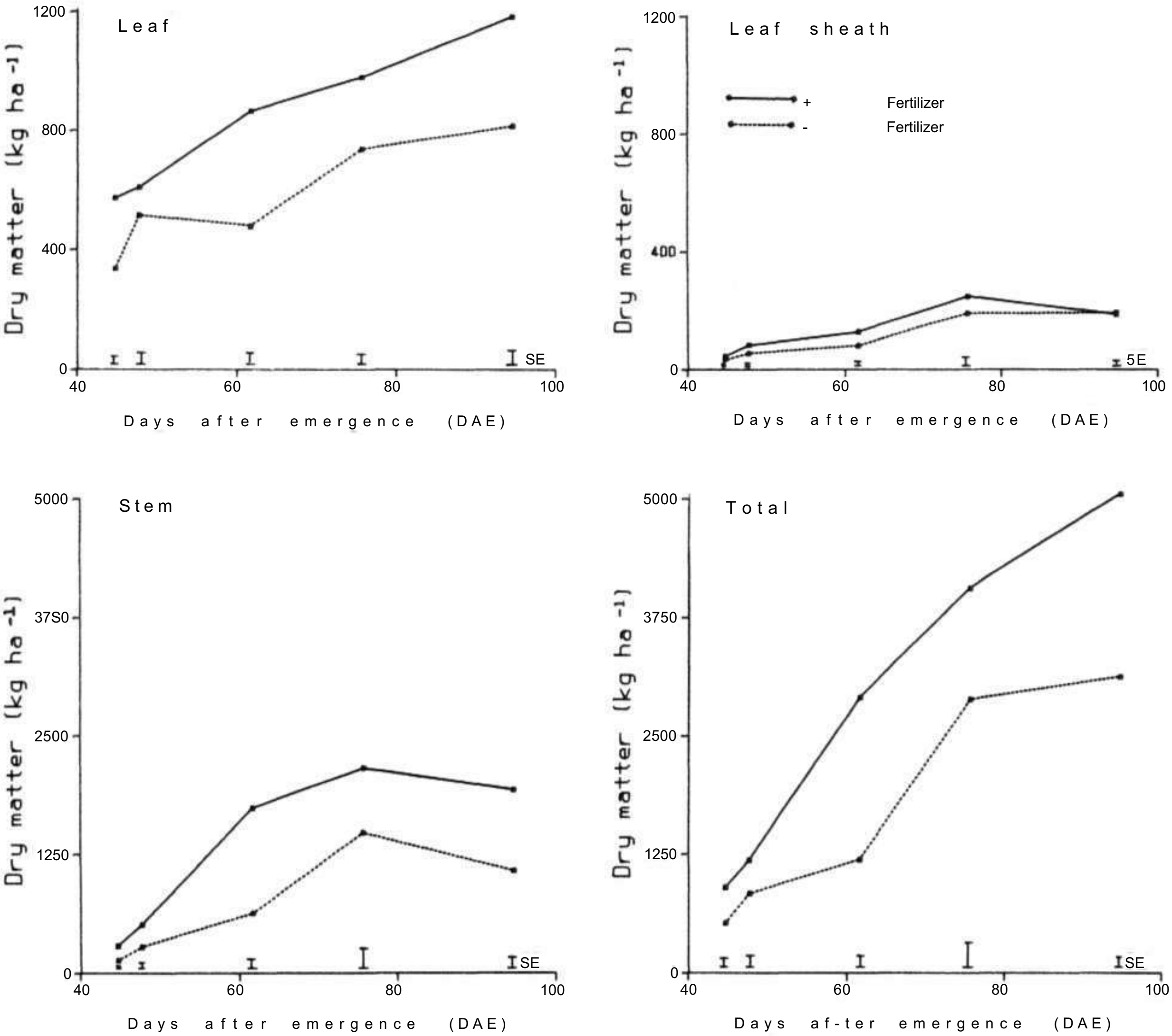


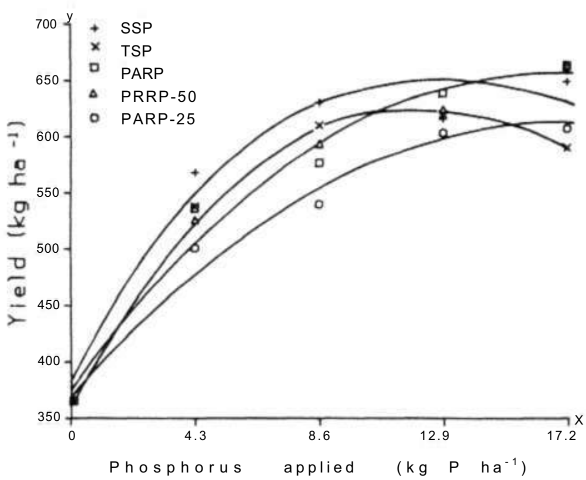
Figure 31. Dry-matter distribution in different plant components of millet cv CIVT, Dosso, Burkina Faso, rainy season 1984.

Nutrients

Phosphorus

We continued research initiated in 1982 and supported by IFDC, on the management of nitrogen and phosphorus in the West African SAT. Our priority is to assess the effectiveness of partially acidulated rock phosphate (PARP) as a source of phosphorus for pearl millet.

In spite of the severe drought this year, our results confirmed the preliminary results obtained in 1983. At Sadore (ISC), pearl millet treated with single superphosphate (SSP) gave similar yields to those obtained using triple superphosphate (TSP), or the two PARP materials, PARP-50 and PARP-25 (i.e., materials prepared by treating rock phosphate with 50 and 25% of the amount of sulfuric acid normally required to convert the relatively insoluble rock phosphate (RP) to water-soluble phosphorus (WSP) (Fig. 32). These results clearly indicate that rock phosphate or PARP are suitable sources of phosphorus at ISC.



$y = 384 + 41.6x - 1.61x^2$ R = 0.93 rse = 42.2

$y = 372 + 43.3x - 1.80\ x^2$ R = 0.99 rse = 13.5

$y = 378 + 34.1x - 1.04\ x^2$ R = 0.97 rse = 27.8

$y = 376 + 35.2x - 1.09\ x^2$ R = 0.98 rse = 22.3

$y = 373 + 29.2x - 0.91\ x^2$ R = 0.98 rse = 19.0

Figure 32. Effect of different sources of phosphorus on grain yield (kg ha^{-1}) of millet, ISC, Niger, rainy season 1984. (TSP - triple superphosphate; SSP= single superphosphate; PAR-50 and PAR-25 = partially acidulated rock phosphate treated with 50 or 25% sulfuric acid; RP = rock phosphate).

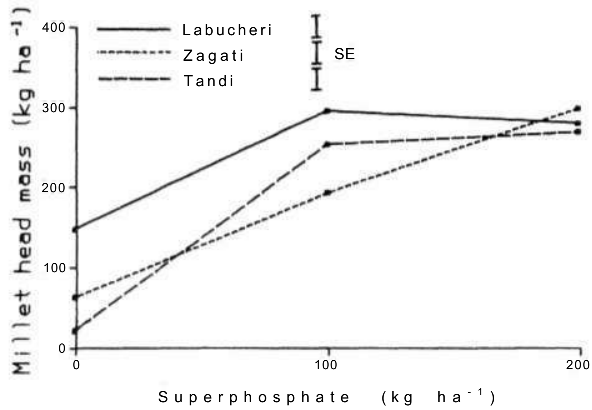


Figure 33. Effect of rate of superphosphate added on pearl millet yield (kg ha^{-1}) on three soil series, ISC, Niger, 1984.

In our experiment at Gobery (100 km SE of Niamey), all the improved sources of P (SSP, TSP, and PARP-40) increased yields to over 500 kg ha^{-1} with 25 kg added P ha^{-1} over the 50 kg ha^{-1} in the control (without added P), but non-treated rock phosphate increased yields only to 250 kg ha^{-1}.

Under the Tropsoils project (Texas A&M University), we are studying the water relations in four of the five soil series found at the ISC. As part of these studies, we applied phosphorus at three rates (0, 7.5, and 15 kg P ha^{-1}) to millet; we also applied urea to all treatments at 46 kg N ha^{-1} as a split application. The results (Fig. 33) provide another example of large responses to fertilizer P, and indicate the need for soil tests to predict fertilizer P requirements.

Losses of Nitrogen

In our IFDC-supported project, we continued our studies on the most appropriate type and method of application of nitrogenous fertilizer for pearl millet. Following the interesting result in 1983 that urea uniformly broadcast on the soil surface was more effective than point placement close to hills sown with millet, in 1984 we compared two different nitrogenous fertilizers, calcium ammonium nitrate (CAN) and urea. Nitrogen application increased yields from 530 kg ha^{-1} to over 700 kg ha^{-1}. CAN seems the more effective fertilizer. Our N analyses show that N losses from split applications, in bands, were 25% for CAN and 35% for urea; 50% of the applied N was lost from urea point-placed close to millet hills, even though split applications were used.

Nitrogen Fixation by Cowpea

Cowpeas fulfil a very important role in cropping systems because of their capability to fix atmospheric nitrogen, and thus improve the fertility of the soil for subsequent cereal crops. This year we initiated an experiment to evaluate the total amount of nitrogen fixed by cowpea as well as the amount of nitrogen left in crop residues after grain harvest.

We established 15 separate crop treatments to compare 4 extra-early, 5 medium-, and 5 long-duration cowpea cultivars, with pearl millet in one treatment as the control. For the experimental site, we used land known to be of low soil-nitrogen status. At sowing we gave a basal application of 400 SSP kg ha^{-1}, and 50 kg N ha^{-1} as urea to the nitrogen treatments; we gave this additional nitrogen (50 kg ha^{-1}) at flowering. Nitrogen fertilizer increased nodule numbers, shoot weight at 4 and 6 weeks, and total dry weight of all cultivars.

Residual Effects of P Fertilizer Application on Cowpea

In 1983 at ISC, we initiated a long-term experiment to determine the residual effects of water-soluble phosphorus applied to cowpea at 0,13, and 26 kg P ha^{-1}. Yields of 5 millet varieties (3/4 HK, CIVT, P Kolo, Souna, and Sadore local), grown in 1984 in sub-plots within the main-plot P treatments of the previous year, showed good residual effects (Fig. 34); grain yields from the areas previously treated with P were double those from the control treatment (without added P).

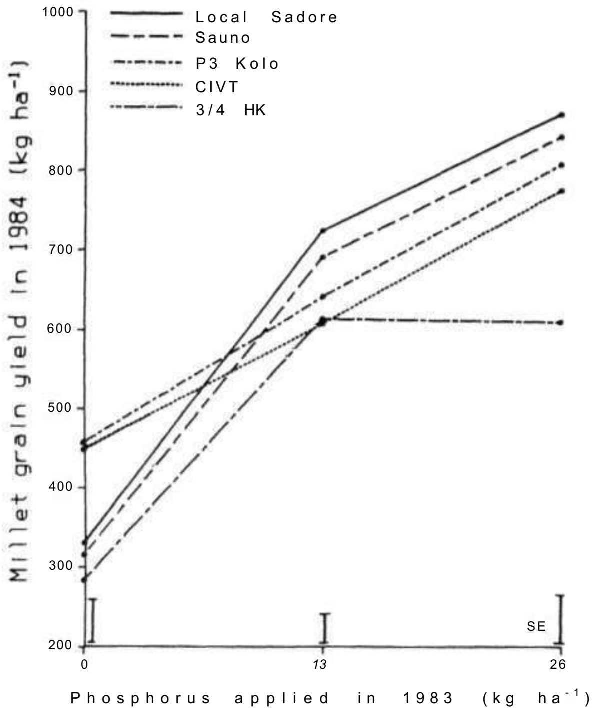


Figure 34. Residual effect of phosphorus applied to cowpea in 1983 on grain yields (kg ha^{-1}) of five millet cultivars, ISC, Niger, rainy season 1984.

Soil Management

Plant-Establishment Studies

Plant-establishment problems on the sandy soils at ISC are usually caused by the combination of soil and climatic factors. Strong easterly winds usually precede rainstorms, causing wind erosion that results in seedlings being sand blasted and buried in the sand. In an exploratory factorial experiment, we studied the effects of several factors: method of pre-sowing tillage, sowing depth, plant spacing, fertilizer addition, and distance from a windbreak, on the establishment, early growth, and yield of a local pearl millet cultivar (Sadore local).

We compared two plant spacings: sowing on hills spaced 1 m apart (a traditional method), and drilling seed in rows 75 cm apart. For both methods, we used a precision planter to ensure consistent seed placement and seeding rate.

During the first 2 weeks of the crop's establishment, two small rainstorms preceded by strong winds provided on opportunity to examine the effects of the treatments on plant stand and height. Tillage method, plant spacing, and distance from the windbreak caused significant effects (Table 42). Plowing and ridging gave a better plant stand and growth than the control (zero tillage) treatment. We attribute the effect of plowing to the reduced bulk density of the surface soil, that facilitated root extension, and that of ridging to reduced wind erosion because of the rougher soil surface. The soil surface in the plowed treatment was as smooth as the surface in the untilled plot. The volume of loosened soil after plowing is much greater than after ridging.

Drilling seeds in rows gave significantly better plant stand than sowing in hills, despite a greater seedling mortality between 7 and 13 DAS. Emergence from hills was lower, but subsequent mortality was also lower because of the mutual protection provided by the cluster of seedlings, that favors the innermost seedlings; plants were significantly taller in hills than in drill rows.

The experiment was located between two windbreaks aligned in a north-south direction. Stand establishment and growth increased with distance from the protected side of the field, but these effects were obscured to some extent by soil heterogeneity. Fertilizer application did not significantly improve stands or height at this early stage in crop development. Interactions, and the effect of sowing depth, were also not significant.

Two weeks after sowing, the crop was thinned to three plants $hill^{-1}$ and a corresponding three plants m^{-1} in drilled rows. During the severe drought in 1984, on average only 190 mm of

Table 42. Effect of cultivation, sowing method, and distance from windward windbreak, on establishment and plant height of millet during the first two weeks after sowing, Labucheri Sand A and B, ISC, 1984.

Treatment	Stand decline (%)		Plant stand at 13 DAS[1] (10^3 ha^{-1})	Plant height at 13 DAS[1] (cm)
	3-7 DAS[1]	7-13 DAS[1]		
Presowing soil preparation				
Plowed	15	-2	149	14.6
Ridged	1	12	151	15.6
Sandfighter	18	19	84	13.1
Nil (zero tillage)	16	14	99	10.8
SE	±4.8	±5.1	±20.9	±1.20
Sowing method				
Hills'	12	-2	103	16.9
Drill rows[1]	13	24	139	10.2
SE	±3.4	±3.6	±14.8	±0.86
Distance from windbreak (m)[3]				
20	6	6	178	14.4
60	11	15	88	11.2
100	20	8	95	12.6
140	12	14	123	15.9
SE	±6.7	±7.2	±29.6	±1.20

1. DAS = days after sowing.
2. Hills, 12500 ha^{-1}; drill rows, 75 cm apart.
3. Distance from eastern windbreak to center of block.

rainfall was used by the crop. The treatment effects observed during stand establishment (Table 42) had disappeared almost entirely by harvest. Hill sowing gave a significantly *(P<* 0.05) higher grain yield (510 kg ha^{-1}) than drilled rows (410 kg ha^{-1}). The addition of 40 kg N ha^{-1} and 17 kg P ha^{-1} also increased grain yields, from 370 to 540 kg ha^{-1} (SE±31 kg ha^{-1} for both comparisons). All other treatments were not significant, except the depth of sowing x fertilizer interaction, which was significant for TDM yield.

Rainfall-Simulation Studies

The soil surface layer at ISC is compact. Typical bulk densities of surface soil range from 1.5-1.7 g cm*3, corresponding to a porosity of 43-36%. Such densities may hamper root development. A weak crust also forms on the soil surface. Cultivation loosens the soil and destroys the crust, but we do not know how long this effect lasts. We therefore studied changes in soil properties after the application to freshly-tilled soil of controlled amounts of rainfall with a rainfall simulator, on a typical sandy soil at ISC. The soil was initially dry, with a bare, weakly-crusted surface. The high rainfall intensity used (100 mm h^{-1}) did not cause runoff even after 2 h of continuous application. Incipient ponding was visible in a few small localized depressions, but disappeared immediately after the rain stopped. Soil-splash erosion, however, was considerable.

Cultivation reduced the bulk density of the surface soil (0-15 cm) to 1.22 g cm^{-3} thus increasing porosity to 54%. Consolidation, resulting from rainfall impact during four rainstorms totalling 100 mm, reduced soil porosity from the initial 54% to 51 ± 1.4%, which was well above the natural level. Penetrometer measurements showed that two months after plowing, soil resistance was still 50% lower in cultivated than in zero-tilled soil.

Long-Term Soil-Management Experiment

In 1984, we started a long-term experiment at ISC to study various soil-management factors: cultivation, mulching, and addition of N and P fertilizer. We are measuring crop growth and water use, and changes of soil physical properties and organic matter. Three runoff plots, of the 'Wischmeier' type, were also included in the design. The experiment is located on sloping land, previously under bush fallow. The cultivation treatments consisted of plowing, ridging, and zero tillage. The mulch treatment consisted of millet stalks (4000 kg ha"1) added before tillage. The fertilizer treatment added 40 kg N ha^{-1} and 17 kg P ha^{-1}. In 1984, we sowed a local millet (cv Sadore) in hills (13300 ha^{-1}).

In this initial year of the experiment, establishment was good. Tillage increased early growth, but the most advanced plants later became most adversely affected by severe drought. The total rainfall from sowing to the end of August was 158 mm.

The crop died from drought before it could produce grain. However, fertilizer application significantly *(P* <0.001) increased dry-matter yields, from 2270 kg ha^{-1} on the control plots to 2990 kg ha^{-1} (SE = ±53). The addition of crop residues significantly *(P* <0.05) increased yield from 2440 kg ha^{-1} to 2820 kg ha^{-1} (SE = ±105).

Changes in soil-moisture content were confined to the top 80-100 cm of the soil profile. The crop extracted moisture at higher rates on the plowed treatment than on the zero-tilled treatment. Almost all rainfall was transpired by the crop. On the bare Wischmeier treatment, 50% of the rainfall was lost by evaporation.

Effect of Cultivation on Water Use

A separate cultivation experiment provided results complimentary to those from the long-term management experiment. We sowed this experiment 9 days earlier, thus allowing the crop to use rainfall that would otherwise have evaporated; this proved crucial because, in contrast to the long-term experiment, the crop produced grain (240 kg ha^{-1} averaged over all treatments). Total rainfall between sowing and harvest was 167 mm.

The cultivation treatments—plowing, ridging, and cultivation—significantly affected the moisture content of the upper 2-m depth of the soil profile. Evapotranspiration by the crop totalled 188, 175, 173, and 169 mm for plowing, ridging, cultivating, and the zero-tillage control respectively. The corresponding TDM yields were 5420, 4900, 4400, and 4190 kg ha^{-1} (SE = ±470), thus indicating good agreement between the effect of the tillage treatments on crop yield and moisture use.

Rejuvenation of Barren Forest Lands

Revegetation experiments were commenced by the Tropsoils Project (Texas A & M University) in the Guesselbodi forest, 30 km northwest of ISC The Guesselbodi forest consists of a mosaic of vegetated and bare areas, the latter resulting from removal by erosion of the thin layer of sandy surface soil that overlies an intractable clay subsoil. Crusting of the exposed clay surface causes most rainfall to be shed as runoff. Improving the infiltration of rain into the soil appeared to be the key requirement for revegetating these bare areas. We therefore examined the effects of two simple treatments, arranged in a 2 x 2 factorial design.

1. Hand tillage, to a depth of 10-15 cm.
2. Mulching with twigs and branches left after timber-cutting of the adjoining forested areas.

In 1983, 10 replicates were established on each of two contrasting environments protected from, or exposed to, natural grazing (by goats). In 1984 we continued measurements on the plots established in 1983; additionally, we commenced similar treatments with three replicates in the grazed and ungrazed situations, to provide both a comparison of the first-season response in another season, and also to provide a comparison with the 2nd year's results from the original plots. We measured natural revegetation only; no fertilizers were applied, nor were seeds introduced. In 1983, the rainfall of 540 mm was about average, and *in* marked *contrast to* the very low rainfall in 1984. Surveys of plant species and biomass produced in the plots, and along fixed *transects* in the natural forest areas were made in 1983 and at the end of the 1984 rainy season.

Natural revegetation did not occur in non-treated areas. Both treatments promoted revegetation (Table 43). During the 1st season, hand tillage was more effective *(P<0.10)* than mulching in promoting biomass production for the experiment established in 1983, but there was no difference between mulching and tillage in the experiment established in the very dry 1984 season. However, during the 2nd season after establishment, the effect of mulching was greater than that of tillage.

The maintained beneficial effects of mulching with time appear to be due to a combination of factors including the stabilized sand and leaf mulch held within the plots, termite activity, decreased soil-surface temperatures, and protection from rain impact. Wind storms are an important factor because they blow sand, leaves, and seeds onto the plots. Because the branch mulch stabilizes these windblown materials, it appears to offer considerable promise for promoting revegetation as it is readily available as a by-product of timber-cutting operations in the forest.

The reduced effectiveness of the tillage-only treatment in the 2nd year (1984) appears also to be due to several factors, including reformation of the surface crust, and the loss of most of the debris that had accumulated in the vegetation in the previous year. This loss of debris was accompanied by an increase in soil-surface temperatures.

Biomass stands in adjacent vegetated areas provide a means to evaluate treatment performance each year. The mulched-plus-tillage treatments established in 1983 performed well, compared with the adjoining vegetated areas in both years.

We determined soil-moisture contents to a depth of 45 cm at approximately 20-day intervals throughout the 1984 rainy season. Soil-moisture contents under newly-treated areas in 1984 showed a similar pattern to that found in 1983. Initially, tillage was more effective than mulching in increasing rainfall infiltration (Fig. 35a); in the 2nd season, however, mulching increased soil-moisture content more than tillage (Fig. 35b).

Table 43. Effect of mulching and hand-cultivation on natural revegetation of eroded areas on a Typic Paleustult[1], Guesselbodi forest, 1983-84.

	Annual biomass production (kg ha^{-1})					
	1983			1984		
Treatment	Mean	SB	CV (%)	Mean	SE	CV (%)
Experiment started 1983[2]						
Nil	0	-	-	0	-	-
Mulch[3]	210	±63	131	150	±42	125
Tillage[4]	440	±112	114	30	±12	159
Mulch + tillage	960	±141	65	310	±56	82
Under adjoining forested area	890	NA[5]	-	200	±31	72
Experiment started 1984[2]						
Nil				0	-	-
Mulch[3]				50	±45	245
Tillage[4]				100	±91	231
Mulch + tillage				80	±28	89
Under adjoining forested area				200	±31	72

1. Family: sandy-skeletal siliceous, isohypothermic.
2. Replication: 20 in 1983, 6 in 1984.
3. Mulch of tree branches and twigs,
4. Hand cultivation to a depth of 10-15 cm.
5. NA = Not available.

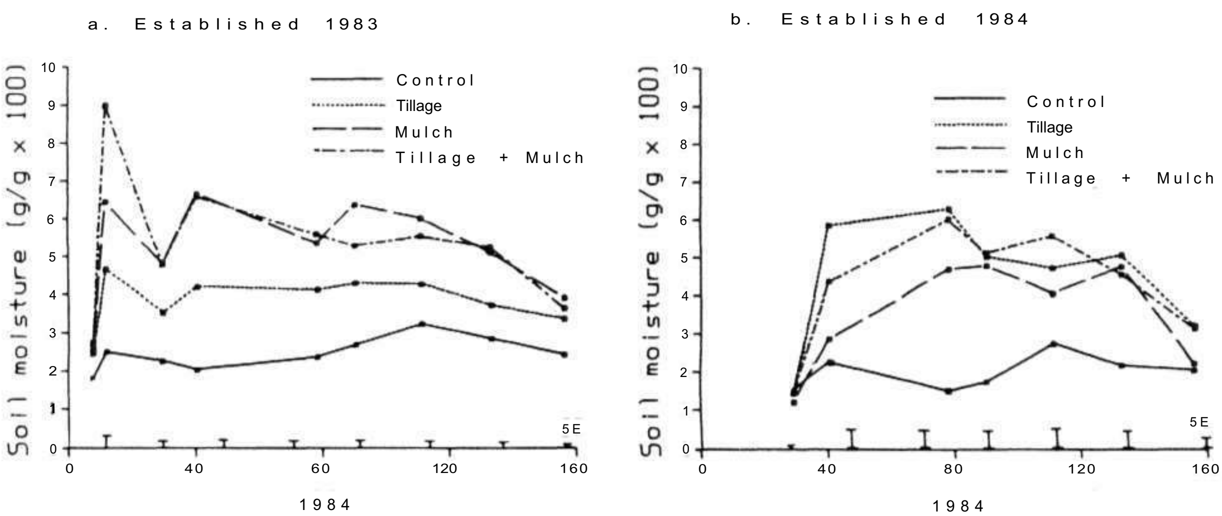


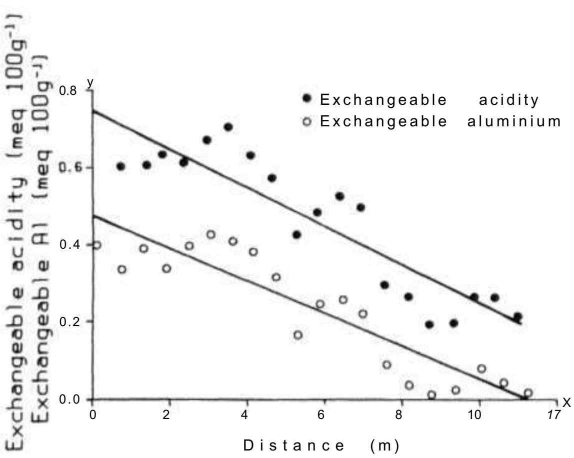
Figure 35. Effect of tillage and mulching on moisture content of surface soil (0-30 cm) during the 1984 season for plots established inside a protective fence in the Guesselbodi forest in (a) 1983, and (b) 1984.

Our studies so far indicate that loss, or recapture of a thin, easily-eroded horizon of sandy soil, is a key factor in the contraction or expansion of the vegetated area in the forest, and that the ecosystem is very fragile.

Sources of Crop Variability

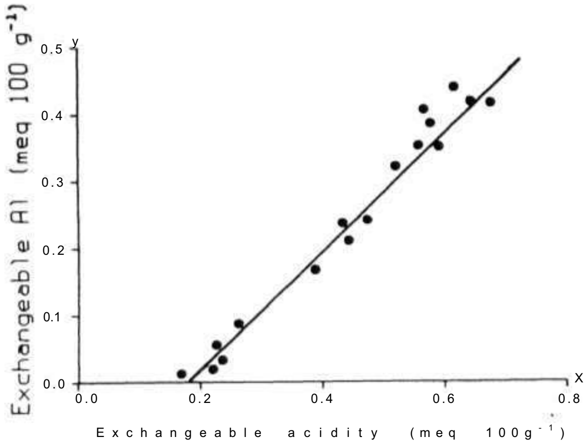
High within-plot variability hinders research at ISC and elsewhere in the Sahel, and also causes substantial losses of crop yield in farmers' fields. In 1983 we collected data to provide examples of the variability over short distances. One such example is shown by the performance of a millet crop on two adjacent plots in a field uniformly sown and treated with fertilizer. In each plot, 49 hills were sown with millet. In the plot with better crop growth, millet plants survived on 44 hills and produced 157 heads. In the plot with poorer growth, plants survived on 11 hills and produced 27 heads. The yield figures are similarly contrasting: for the better plots, head yields ranged from 1160 to 1300 kg ha^{-1}, and 120 to 2340 kg ha^{-1} in the poorer plots.

About 5% of the 2-ha field containing these plots had growth similar or worse than that on the poorer plot, and about 9% was occupied by crops similar to the better plot. We are concentrating on determining the cause of extremely poor growth.



1. y = 0.728-0.048x r = 0.92 rse = 0.07
2. y = 0.424-0.032x r = 0.93 rse = 0.06

Figure 36. Exchangeable acidity (1) and aluminium (2) along a transect in a research field, ISC, Niger.



1. y = -0.147+0.823x r = 0.99 rse = 0.04

Figure 37. Exchangeable A1 versus exchangeable acidity from a transect in a research field, ISC, Niger.

Soil under the poorest-yielding crops has lower pH, and higher exchangeable acidity and aluminium, than soil under the higher-yielding crops; this is illustrated by soil analysis along a transect between sites with poor and good stands of millet (Fig. 36). Exchangeable aluminium was highly correlated with exchangeable acidity (Fig. 37). Similar results were also obtained in a farmer's field.

We are further investigating the relative importance of aluminium toxicity and other problems associated with acid soils, as well as soil physical characteristics, as possible causes of particularly poor millet growth. Pot studies are in progress to study the pH-related problems.

Cropping Systems

Cowpea Cultivars for Intercropping

We grouped a total of 270 cowpea cultivars of varying plant types and maturities in 15 different trials in which we compared cultivar performance under sole and intercropping with a standard cultivar of millet. The row arrangement in the intercrop was 1:1 milletxowpea.

In one experiment, 33 cowpea cultivars produced grain yields between 600 and 1500 kg ha^{-1} in sole cropping; 20 of these cultivars produced respectable yields in the intercrop despite the severe drought stress. The long-duration local variety was severely affected by drought, and produced no grain under either cropping system. All cultivars that produced more than 1000 kg ha^{-1} of grain were the shorter-duration cultivars needing only 55-70 days to maturity.

Cowpea yields under intercropping were low, and usually less than 50% of the yields in sole cropping. The correlations between inter- and sole-crop yields of the cultivars were positive but nonsignificant. Similarly, rank correlations were not significant. The effects of severe drought prevented detection of any component crop interaction.

We also examined six cowpea cultivars of different maturities in combination with two contrasting pearl millet cultivars. The average cowpea yield of the sole crops was 543 kg ha^{-1}. Yields of the cowpea intercrops ranged from 29 to 46%) of the sole-crop yields. Millet yield under intercropping ranged from 12 to 76% of sole-crop yield. Cowpea intercrop yields were closely correlated with sole-crop yields (r = 0.95). Cowpea IT82D 716, a medium-duration and erect cultivar, yielded above average when intercropped with either millet cultivar and significantly better than TN88-63, an improved local cultivar.

Of the plant characteristics measured, pod production per unit area appeared to provide the most sensitive index of stress caused by intercropping. Only 1 out of 10 combinations showed an overall advantage of 19% or more; these usually involved an erect determinate cowpea and a tall, leafy, local millet cultivar.

Dual-Purpose Cowpea

In Niger, cowpea is grown for its grain, or leaf as a green vegetable, and for forage. Preferences for individual cowpea products differ from place to place but in most areas cowpea cultivars that retain their foliage at maturity are generally preferred. All the cultivars we evaluated were also rated for their ability to retain their leaves 60 days after sowing (DAS), and at harvest.

The rating was based on a visual score of 1 to 5 (1 = all leaves shed and 5 = more than 95%; leaves retained), and actual measurements of a few cultivars in large plots. Thirteen photoperiod-insensitive cultivars were rated 4 or 5, and also produced acceptable grain yields. The hay yield of seven promising cultivars ranged from 800 to 2400 kg TDM ha^{-1} in sole cropping and 300 to 900 kg TDM ha^{-1} when intercropped. Such cultivars are likely to be of tremendous advantage to the small farmer in the Sahel.

Cowpeas in the Millet-Based Cropping System in Niger

Almost all cowpea production in Niger originates from cowpea/cereals intercrops. Observations of farmers' fields, and economic surveys, indicate that the intensity of millet/cowpea intercropping ranges from 40 to 70%. The most prevalent cowpea cultivars are the spreading photosensitive types, often grown at very low plant populations. In the past, cowpea grown in Niger was mainly exported to neighboring countries, because little was consumed locally. However, the crop is fast assuming importance in the diet of Nigeriens. The campaign by the Government to educate the people on the nutritional value of cowpeas has been well received, as evidenced by the commonly-seen dishes of rice and cowpeas sold at street corners and in market places. Red-seeded, medium-sized varieties are used for this dish, but the most popular are medium to large, white, rough-seeded varieties.

Farm Power and Equipment

Adaptation of the Sandfighter to Animal Traction for Use in the Sahel

Sand blasting and burial of millet seedlings continues to prevent crop establishment often forcing farmers to resow their crops. Such later sowings usually result in lower yields. We have therefore investigated the use of animal- and tractor-drawn 'sandfighters' to stabilize the sandy soils at ISC.

The sandfighter is an implement that when used on wet soils, makes many small depressions that remain stable as the soil dries. This increased surface roughness gives protection against wind erosion. For the best protection, the implement must be used on wet soil at the same time as sowing, i.e., as soon after rain as possible.

We have developed a new form of animal-drawn sandfighter with removable tines that cut four rows of paired holes on each rotation, leaving a 1 m x 0.75 m plant spacing pattern. The paired holes are about 10cm apart to allow for separate seed and fertilizer placement. We will test this new sandfighter during the 1985 rainy season.

Animal Traction for Millet Farming

Animal traction is a suitable form of agricultural mechanization in sub-Saharan Africa, but its adoption for cultivation in West Africa decreases from the subhumid to the semi-arid zones. Animal traction was introduced into Niger about 1960, but it is still very rarely used in areas where rainfall is less than 600 mm. We are therefore studying ways to introduce animal traction into new areas. Our studies include the development of methods employing a single animal instead of a pair.

We are also examining the effect of the use of animal traction in reducing labor requirements for crop production. This year, we evaluated six cultivation methods at ISC; these included traditional hand-cultivation, and five animal-traction methods involving oxen or donkeys (Table 44) for primary tillage. All subsequent operations (sowing, weeding, and thinning) were done in the same way on all treatments; we sowed and thinned by hand, but used donkey-drawn cultivators equipped with sine hoes for weeding.

We started primary cultivations on the experiment in the beginning of July, and sowed millet by hand in hills (10000 ha^{-1}), with SSP (200 kg ha"[1]) and CAN (100 kg ha^{-1}) fertilizers.

Table 45 shows the labor inputs required for the various farming operations. The use of oxen

Table 44. Cultivation methods tested at ISC, Sadore, 1984.

Tillage operation	Implement	Power source	Animal live weight (kg)
Scraping	Hand hoe	Man	-
Plowing	Sine hoe[1]	1 Donkey	100-140
Plowing	Moldboard plow	2 Oxen	390-430
Scraping	Sine hoe	1 Donkey	100-140
Ridging	Moldboard plow	2 Oxen	390-430
Scraping	Canadian cultivator	2 Oxen	390-430

1. Three-toothed cultivator.

for land preparation, i.e., plowing or ridging, reduced the labor requirement for supplemental soil preparation and also reduced the need for labor for a second sowing because of better crop emergence in soil ridged by oxen. We reduced total seasonal labor requirement by 25% by using the combination of oxen power and ridging.

Drought stress in October severely reduced yields, which were 104-137 kg ha^{-1} of grain, and 720-1000 kg ha^{-1} of straw; tillage method did not significantly affect yield.

Component Research—Agronomy in Mali

The agronomy program in Mali aims to develop improved millet- and sorghum-based cropping

Table 45. Labor time required for soil preparation and total cultivation operations by different methods, ISC, Sadore 1984[1].

Method	Labor time (man hours ha^{-1})	
	Soil preparation	All operations
Hand tillage	28 (± 13)[2]	153 (+12)
Plowing (donkeys)	24 (± 8)	148 (±25)
Plowing (oxen)	14 (± 3)	142 (± 18)
Scraping (donkeys)	26 (± 9)	133 (± 14)
Ridging (oxen)	16 (± 4)	114 (± 14)
Scraping (oxen)	12 (± 7)	144 (±22)

1. Plot size 45 x 45 m, eight replications.
2. Figures in parantheses are SEs.

systems for rainfed farming. We give major emphasis to studies on intercropping systems, and to the agronomy of improved cultivars of sorghum and other component crops.

Intercropping Systems

In southern Mali, the normal annual rainfall exceeds 1000 mm, and the growing season is long. Maize/millet is the major intercropping system that traditionally follows cotton. This system has considerable potential for intensification, because the temporal complementarity of a short-duration maize cultivar intersown with longer-duration 'Sanio' pearl millet makes the best use of existing resources. In 1982 we started to define the requirements of this cropping system to optimize the overall productivity. Using factorial experiments, we are examining such factors as time of sowing of the millet intercrop, density of both component intercrops, and rate of fertilizer N applied to maize.

Yields of the millet intercrop increased with earliness of sowing date at both Sotuba and Sikasso (Table 46). But the earliest sowing date, when millet was sown simultaneously with maize, caused a marked reduction in maize yields. Although sowing delays reduced millet yields, the intermediate date (when the maize reached the 3- or 4-leaf stage) gave millet yields of 500 kg ha^{-1}.

Table 46. Effect of pearl millet sowing date on grain yield (kg ha^{-1}) from maize/millet intercrops, Sotuba and Sikasso, Mali, 1982 and 1984[1].

		Grain yield (kg ha^{-1})			
		Sotuba		Sikasso	
Year	Millet sowing date	Maize	Millet	Maize	Millet
1982	At maize sowing date	2480	1860	1600	810
	Maize at 4-leaf stage	3660	510	1900	530
	Maize at 6-leaf stage	3400	110	2040	270
	SE	±96	±63	±103	±70
1984	Maize at 3-leaf stage	1110	1040	1020	1240
	Maize at 6-leaf stage	1360	520	980	710
	SE	±48	±50	±115	±75

1. Total rainfall: Sotuba—1982, 928 mm; 1984, 850 mm; Normal, 1100 mm. Sikasso—1982, 1112 mm; 1984, 860 mm; Normal, 1200 mm.

Table 47. Effect of intercrop population on grain yield (kg ha^{-1}) from maize/millet intercrops, Sotuba and Sikasso, Mali, 1982 and 1984.

		Grain yield (kg ha^{-1})			
		Sotuba		Sikasso	
Year	Population (plants ha^{-1})	Maize	Millet	Maize	Millet
1982	Intercrop millet population varied				
	15000	3240	650	1830	450
	30000	3110	1010	1880	620
	SE	±30	±80	±120	±90
1984	Intercrop maize population varied				
	25000	970	870	920	870
	50000	1500	680	1080	1080
	SE	±48	±50	±115	±75

Increasing the seed rate of the millet intercrop increased its yield without markedly reducing the yield of the maize main crop (Table 47). Increasing maize density to the normal for a sole crop increased maize yield and decreased millet yield at Sotuba (Table 47), but did not cause significant effects at Sikasso.

Although maize in southern Mali is usually sown in a rotation, following a well-fertilized cotton crop, it generally receives some additional fertilizer. We therefore compared two levels of additional nitrogen in the maize/millet intercrop system: the recommended rate of 40-60 kg N h^{-1}, and twice this rate. Maize responded to higher fertilizer levels at both the locations in the wetter 1982 season, but not in the drier 1984 season (Table 48). Added fertilizer increased millet yield at Sikasso in 1982. However, on average, the higher rate of fertilizer N increased yields only slightly over those with the recommended rate. Interactions between the various management factors were not significant across locations and seasons, but there were some indications that maize responded better to fertilizer N when millet is sown later, and that the later-sown intercrop yield could be maintained by increasing millet density.

Table 48. Effect of fertilizer N rates on grain yield (kg ha^{-1}) from maize/millet intercrops, Sotuba and Sikasso, Mali, 1982 and 1984.

		Grain yield (kg ha^{-1})			
	Fertilizer N	Sotuba		Sikasso	
Year	(kg ha^{-1})	Maize	Millet	Maize	Millet
1982	60	2950	790	1760	470
	120	3400	860	1940	590
	SE	±60	±100	±36	±27
1984	40	1180	690	1060	970
	80	1320	810	1300	980
	SE	±133	±87	±125	±47

From these studies across locations and seasons we conclude that, for optimum productivity of the millet/maize intercrop, millet should be sown when the maize is at the 3-4 leaf stage, maize and millet should be sown at their normal sole-crop density (50 000 and 30 000 plants ha^{-1}, and that maize should receive the recommended rate of fertilizer N (40-60 kg N ha^{-1}).

We will extend our present small, plot studies to operational-scale evaluation of improvements to the traditional systems at different locations.

Sole Crops

Previous agronomic research on individual crops has been mainly restricted to local cultivars of sorghum and millet. During 1984, we evaluated for the first time improved breeding materials developed by our sorghum breeding program in Mali for their agronomic performance.

Agronomic trials were also initiated on fonio (*Digitaria exilis)* and bambara groundnut (*Vigna subterranea),* two less-studied but important rainfed crops of Mali.

Sorghum

We evaluated three improved sorghums under two plant-population levels and two rates of fertilizer N at Sotuba, with CSM 388 (a local Malian sorghum) used as a control. Table 49 shows the performance of these four cultivars during a year when the total rainfall was about 850 mm (normal 1100 mm). Although the total rainfall was less than normal, the distribution was good with adequate late rains.

The new sorghum cultivars flowered and matured earlier than the local control. They were also shorter, but their grain yields were not significantly greater than that of CSM 388 which yielded well over 2000 kg ha^{-1}. The longer-duration CSM 388 did not, therefore, suffer from moisture deficiency during the critical flowering period. We expect that the improved shorter-duration cultivars will perform better during years when the rains stop early—a characteristic of the recent drought years.

Increased population did not increase yields, indicating that the present recommendation of 50 000 plants ha^{-1} is sufficient, at least in years of

Table 49. Effect of plant population and fertilizer N on days to 50% flowering, plant height, and grain yield (kg ha^{-1}) of four sorghum cultivars, Sotuba, Mali, 1984.

Treatments	Days to 50% flowering	Plant height (cm)	Grain yield (kg ha^{-1})
Cultivars			
83 F_4 24 VC	64	180	2360
83 F_6 225 VC	68	142	2550
83 F_6 108 VC	79	140	1540
CSM 388	82	410	2310
SE		±4	±172
Population (plants ha^{-1})			
60 000	74	221	2130
120000	73	216	2260
SE		±3	±122
N applied (kg ha^{-1})			
0	74	217	2130
40	73	219	2260
SE		±3	±122

moderate rainfall. The lack of a response to added fertilizer N reflects the residual effect of legumes grown at this site in previous years.

Fonio (*Digitaria exilis*)

Fonio, also known as hungry rice, is an important crop in northern Mali. It is normally sown immediately after the first rains, before millet and sorghum, to provide food early in the season. To examine the potential for improving its productivity, we evaluated the crop at Cinzana research station under two plant populations, three nitrogen, and two phosphate fertilizer rates (Table 50). The rainfall in Cinzana during the growing season (550 mm) was below normal (700 mm) and erratic. Early in the season, we observed that the vegetative growth of the crop responded to sowing density and fertilizer, but higher sowing density and fertilizer rates caused the crop to suffer more from stress during the mid-season drought.

Table 50. Effect of seed rate, N, and P fertilizers on grain and fodder yields (kg ha^{-1}) of fonio (*Digitaria exilis*), Cinzana, Mali, 1984.

	Yield (kg ha^{-1})	
Treatment	Grain	Fodder
Seed rate (kg ha^{-1})		
15	580	2770
45	600	2610
SE	±21	±213
N applied (kg ha^{-1})		
0	670	2870
20	560	2500
40	530	2630
SE	±33	±170
P applied (kg ha^{-1})		
0	620	2600
20	560	2740
SE	±27	±137

Bambara Nut (*Vigna subterraned*)

Bambara nut is also an important crop in northern Mali. We examined its response to plant population and fertilizer rates in Koporo, where the rainfall during the year was about 450 mm (normal 600 mm). The crop responded to higher sowing density, but inputs of N or P did not cause significant increases in yields (Table 51).

Table 51. Effect of plant population, N, and P fertilizers on grain yields (kg ha^{-1}) of bambara groundnut (*Vigna subterranea*), Kaporo Mali, 1984.

Treatments	Grain yield (kg ha^{-1})
Population (plants ha^{-1})	
100 000	280
200 000	450
300 000	550
SE	±107
N applied (kg ha^{-1})	
0	410
23	450
SE	±31
P applied (kg ha^{-1})	
0	±420
20	420
40	440
SE	±39

Workshops, Conferences, and Seminars

ICAR/ICRISAT Joint Meeting on Agroclimatology

The objectives of the meeting were to focus attention on the need for climatic data analysis in agricultural decision-making processes, both in operational and strategic terms, and to provide an opportunity for discussion on agroclimatic research for dryland agriculture. The 38 participants represented 18 institutes and universities in India, including different centers of the All India Coordinated Agrometeorology Project, whose coordinating cell is based at All India Coordinated Research Project on Dryland Agriculture (AICRPDA), now Central Research Institute for Dryland Agriculture (CRIDA), other institutes involved with ICRISAT in its cooperative agroclimatic project, and ICRISAT staff. The meeting was held 21-23 February at ICRISAT Center, and 24 February at the All India Coordinated Agrometeorology Project Center in Hyderabad. The participants compiled and analyzed existing meteorological data from their research centers using computer programs available from ICRISAT. They also worked on instruments used in agrometeorological observatories, and collected a minimum set of climate, soil, and crop canopy data to evaluate the response of crops to environmental conditions.

Participants agreed that the main areas of cooperation will be: analysis of climatic data, updating and exchange of meteorological data collected at different research stations, cooperative crop-weather response evaluation studies, and the exchange of crop-weather modeling research information. They also agreed to hold joint meetings and seminars.

The need to train agrometeorological project personnel in data analysis, microclimatological studies, and crop modeling were discussed. The meeting also emphasized methodology, standardization of instrumentation, and the adoption of uniform data acquisition techniques at all cooperating centers. It was felt that understanding the agroclimatology of a region should help rationalize the use of dryland farmers' scarce resources.

Workshop on Intercropping in the Saheiian and Sahelo-Sudanian Zones of West Africa

Organized jointly by ICRISAT Saheiian Center, the Institut du Sahel (INSAH) and the International Development Research Centre (IDRC), this workshop was held 7-10 November in Niamey, Niger.

The objectives of the workshop were: to review current and past research on intercropping in the region; to highlight methodology, design, and experimental techniques used in intercropping research; and to discuss research methodologies appropriate to specific situations.

Fifty participants from Burkina Faso, Cameroon, France, India, Mali, Mauritania, Niger, and Nigeria participated in the workshop, and thirteen papers were presented. Working groups discussed the importance of both sole and intercropping research. A final report summarized the recommendations of the workshop: participants made a strong statement that intercropping systems warranted thorough testing as cropping systems for increasing food production in the region. The proceedings will be published by INSAH.

Looking Ahead

Agroclimatology. We will continue our efforts in agroclimatic description to assist in determining cropping production potentials across the SAT. Collaborative research will continue on soil-plant-atmosphere emphasizing responses of crops to drought stress, evapotranspiration-yield relations, and water-use efficiency. We will also continue to collect standard data sets to develop and validate pearl millet and groundnut simulation models. We have started to collect basic data sets relevant to chickpea modeling. Applications of sorghum and pearl millet models to assess the production potential in a range of agroclimatic environments will receive increasing attention.

Soil physics and conservation. We will continue to collect baseline data for the quantitative assessment of soil loss and runoff potentials for important SAT soils, with major emphasis on Alfisols. We will focus our activities on crust management, mulching, and varying intensities of primary and secondary tillage. Our simulation and modeling efforts will continue, particularly for prediction of runoff. The runoff model based on the curve-number technique and the soil moisture accounting procedure, originally developed and extensively tested for Vertisols, will now be tested with data from Alfisol watersheds at ICRISAT Center and from the Indian Council of Agricultural Research (1CAR) Cooperating Centers.

Soil fertility and chemistry. We will continue to study nutrient x water interactions in studies of the factors limiting the availability of nutrients in the soil. The studies on nitrogen will be assisted by our collaboration with IFDC which is using ^{15}N to examine fertilizer efficiency over a wider range of environments. Our long-term experiments on K and P on Alfisols and crop rotations on Vertisols, the latter handled collaboratively with Cropping Systems, will continue with increasing emphasis on the long-term effects of treatments on soil fertility.

Land and water management. We will continue current studies on water resources development, supplemental irrigation, and tillage, and will initiate studies on the land management of shallow vertic soils. We will be terminating the hydrologic studies on the Vertisol watershed after the 1984/85 rainy season.

Cropping systems. We will continue operational-scale evaluations of the most promising cropping systems at ICRISAT Center for one more year in order to ensure that measurements of the systems' performances are obtained over a sufficient number of years. We will also continue operational-scale evaluations at our on-farm locations of Begumganj and Phanda in Madhya Pradesh, and Talod in Gujarat, and will initiate similar studies on Vertisols at Adgaon in Maharashtra. We are also commencing research on agroforestry in which we will explore the potential of introducing multipurpose perennial species into the most appropriate annual crop systems. Initial emphasis will be on *Leucaena leucoephala,* with fodder as the major product. Experimentation will be multidisciplinary, involving agronomy, to monitor water runoff and soil loss, changes in soil physical properties, and soil nutrient status. Work will also commence on methods for controlling perennial weeds such as *Cyperus* and *Cynodon.*

Farm power and equipment. We will expand our cooperation with research institutions of the Indian national program and will test promising machinery designs at Research Centers as well as on-farm locations. Evaluations will also include implements recommended for dryland agriculture by those institutions. We will continue field experiments on integrated weed management, fertilizer placement, soil crusting, primary tillage, and pest management equipment in cooperation with scientists from other disciplines. We will maintain our technical support to those small industries in India that are adopting proven designs for commercial exploitation.

Publications

Institute Publications

El-Swaify, S.A., Walker, T.S., and Virmani, S.M. 1984. Dryland management alternatives and research needs for Alfisols in the semi-arid tropics: an interpretive summary of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 38 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 Mar 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT. 212 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT. 322 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Proceedings of the Workshop on Watershed-based Dryland Farming in Black and Red Soils of Peninsular India, 3-4 Oct 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT. 95 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. El portaherramienta de ruedas tirado por animales. In Es. Information Bulletin no. 8. Patancheru, A.P. 502 324, India: ICRISAT. 12 pp.

Jha, D., and Sarin, R. 1984. Fertilizer use in semi-arid tropical India. Research Bulletin no. 9. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 76 pp.

Tandon, H.L.S.,and Kanwar, J.S. 1984. A review of fertilizer use research on sorghum in India. Research Bulletin no. 8. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 59 pp.

Journal Articles

Bansal, R.K., and Rego, T.J. 1984. Animal drawn fertilizer applicators. Pages 3-24 *in* Fertilizer application equipment for small farmers. Rome, Italy: FAO.

Bansal, R.K., and Thierstein, G.E. 1984. Metering granular fertilizer with an oscillatory mechanism. Journal of Agricultural Engineering 21(1-2):1-8.

Dalai, R.C., Sahrawat, K.L., and Myers, R.J.K. 1984. Inclusion of nitrate and nitrite in the Kjeldahl nitrogen determination of soils and plant materials using sodium thiosulphate. Communications in Soil Science and Plant Analysis 15:1453-1461.

Huda, A.K.S., Madhusudan Reddy, D., and Seetharama, N. 1983. Effect of moisture stress on yield components of *Sorghum bicolor* (L.) Moench. Sorghum Newsletter 26:129-130.

Kanwar, J.S., Rego, T.J., and Seetharama, N. 1984. Fertilizer and water-use efficiency in pearl millet and sorghum in Vertisols and Alfisols of semi-arid India. Fertiliser News 29(4):42-52.

Kumar, J., Gowda, C.L.L., Saxena, N.P., Sethi, S.C., Singh, U., and Sahrawat, K.L. 1983. Effect of salinity on protein content and seed size of chickpea (*Cicer arietinum* L.). Current Science 52:82-83.

Moraghan, J.T., Rego, T.J., and Buresh, R.J. 1984. Labeled nitrogen fertilizer research with urea in the semi-arid tropics. III. Field studies on Alfisol. Plant and Soil 82:193-203.

Moraghan, J.T., Rego, T.J., Buresh, R.J., Vlek, P.L.G., Burford, J.R., Singh, S.,and Sahrawat, K.L. 1984. Labeled nitrogen fertilizer research with area in the semi-arid tropics: II. Field studies on a Vertisol. Plant and Soil 80:21-33.

Rao, M.R., and Morgado, L.B. 1984. A review of maize-beans and maize-cowpea intercrop systems in the semi-arid Northeast Brazil. Pesquisa Agropecuaria Brasileira, 19(2):179-192.

Sahrawat, K.L. 1983. Nitrogen availability indexes for submerged rice soils. Advances in Agronomy 36:415-451.

Sahrawat, K.L. 1984. Potassium determination in grain samples using the non-digestion (dilute HC1 extraction) method. Communications in Soil Science and Plant Analysis 15:81-86.

Sahrawat, K.L. 1984. Effects of temperature and moisture on urease activity in semi-arid tropical soils. Plant & Soil 78:401-408.

Sahrawat, K.L., and Keeney, D.R. 1984. Effects of nitrification inhibitors on chemical composition of plants: a review. Journal of Plant Nutrition 7:1251-1288.

Singh, U., Sahrawat, K.L., Jambunathan, R., and Burford, J.R. 1984. The use of hydrogen peroxide for the digestion and determination of total N in chickpea *(Cicer arietinum* L.) and pigeonpea *(Cajanus cajan* L.). Journal of the Science of Food and Agriculture 35:640-646.

Sivakumar, M.V.K., and Virmani, S.M. 1984. Crop productivity in relation to interception of photosynthetically active radiation. Agricultural and Forest Meteorology 31:131-141.

Squire, G.R., Gregory, P.J., Monteith, J.L., Russell, M.B., and Piara Singh. 1984. Control of water use by pearl millet *(Pennisetum typhoides).* Experimental Agriculture 20:135-149.

Verma, P.K., Wade, L.J., Peacock, J.M., Seetharama, N., Sai Prasad, J., and Huda, A.K.S. 1983. Leaf area response to water and nitrogen stress in sorghum. Sorghum Newsletter 26:130-132.

Conference Papers

Bhattacharjee, J.C., and Landey, R.J. 1984. Minimum data sets for agrotechnology transfer on Vertisols and associated soils in India. Pages 11-23 *in* Proceedings of the Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 Mar 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Hardiman, R.T., and Willey, R.W. 1984. Cropping systems for increasing the production of groundnut, chickpea, and pigeonpea in India. Pages 23-26 *in* Grain legumes in Asia: summary proceedings of the Consultative Group Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, Pigeonpea), 11-15 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Hilda, A.K.S., Sivakumar, M.V.K., Alagarswamy, G., Virmani, S.M., and Vanderlip, R.L. 1984. Problems and prospects in modeling pearl millet growth and development: a suggested framework for a millet model. Pages 297-306 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Huda, A.K.S., Sivakumar, M.V.K., Virmani, S.M., Seetharama, N., Sardar Singh, and Sekaran, J.G. 1984. Modeling the effect of environmental factors on sorghum growth and development. Pages 277-287 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Huda, A.K.S., and Virmani, S.M. 1984. A sorghum simulation model, SORGF, as a research tool in agrotechnology transfer. Page 79 *in* Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 Mar 1983, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Kanemasu, E.T., Singh, P., and Chaudhuri, U.N. 1984. Water use and water-use efficiency of pearl millet and sorghum. Pages 175-181 in Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Seetharama, N., Mahalakshmi, V., Bidinger, F.R., and Sardar Singh. 1984. Response of sorghum and millet to drought stress in semi-arid India. Pages 159-173 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Sivakumar, M.V.K., Huda, A.K.S., and Virmani, S.M. 1984. Physical environment of sorghum- and millet-growing areas in South Asia. Pages 63-83 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

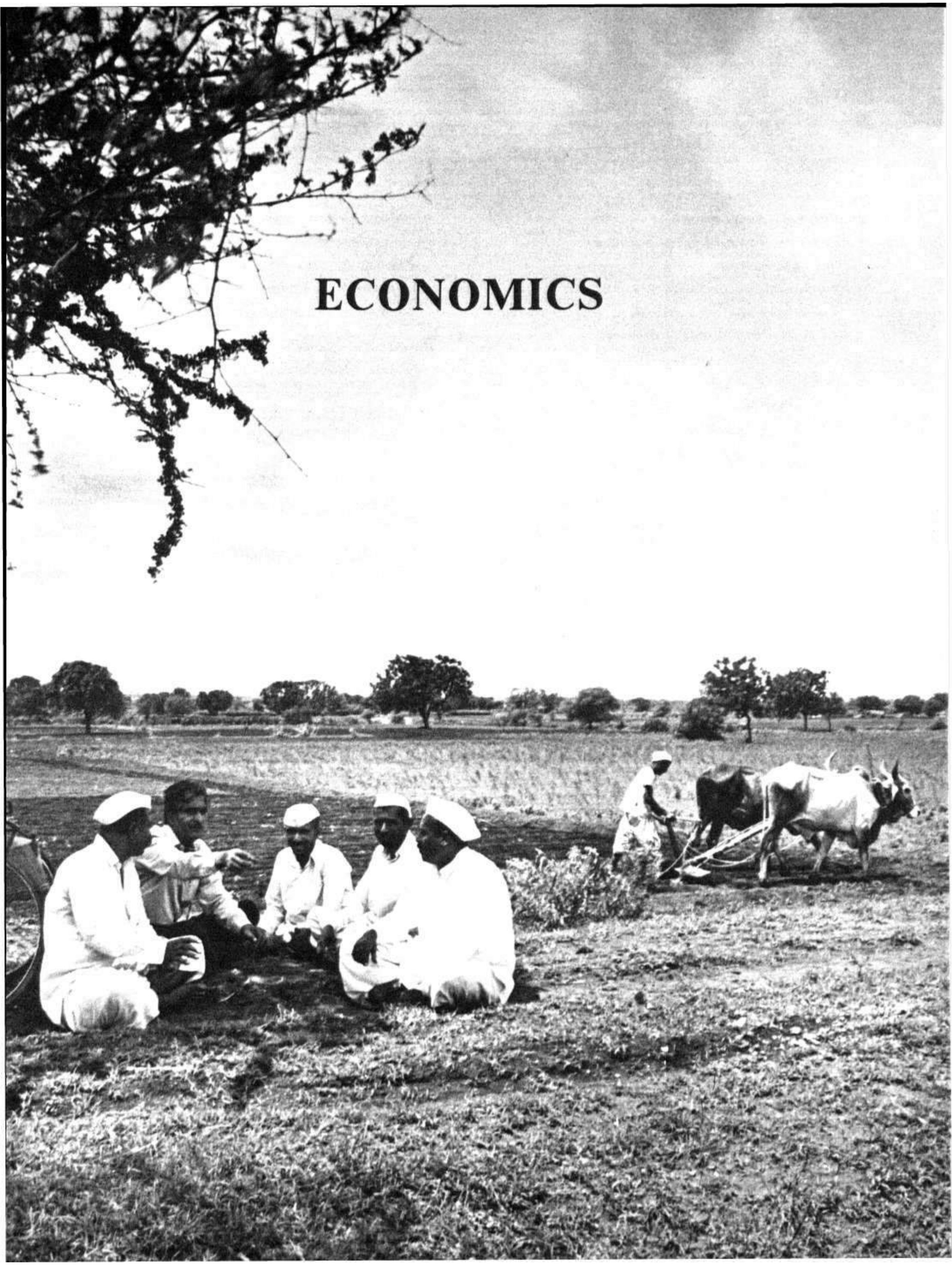
Srivastava, K.L., Virmani, S.M., and Walker, T.S. 1984. Farming systems research in a watershed framework: experience related to Vertisol management in semi-arid tropical India. Pages 352-371 *in* Animals in the farming system: Farming Systems Research Symposium, 31 Oct-2 Nov 1983, Kansas, USA. Manhattan, Kansas, USA: Kansas State University.

Virmani, S.M. 1984. Agroclimatological research in the service of the sorghum and millet farmer: need for a network. Pages 317-322 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Theses

Jarwal, S.D. 1984. Canopy architecture, light interception, water use, and dry matter production relationships in pearl millet (*Pennisetum americanum* L. Leeke). Ph.D. thesis, Haryana Agricultural University, Hisar, Haryana, India.

ECONOMICS



Contents

Cover photo: ICRISAT researcher discussing deep Vertisol technology with respondents from Shirapur village, India.

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ECONOMICS

As researchers at 1CRISAT Center advance their work, the number of technology options that are of potential use to farmers increases. Accordingly, technology assessment assumes increasing importance in the work of the Economics Program in India and West Africa, while fewer studies on behavior and traditional resource management are undertaken.

Technology-assessment studies draw from a wide variety of data sources ranging from on-farm tests and farm surveys to secondary data from published statistics and scientific surveys. These wide-ranging studies on performance, impact, and technology prospects provide us with feedback to help researchers and decision makers ensure relevance in direction and to determine priorities in their work.

Technology Assessment

On-Farm Tests of New Varieties in West Africa

On-farm tests focused on the evaluation of new sorghum varieties, and the measurement of factors causing the difference in yields of new varieties between those grown in farmers' fields compared to their research station yields.

The white-sorghum varieties ICSV 1002 HV and ICSV 1003 HV grown at 5 levels of fertilizer application were tested by nearly 50 farmers in the Sudanian Yako villages, and the varieties ICSV 1002 HV and ICSV 1004 HV by a similar number of farmers in the Guinean Boromo villages.

The plot size for each subplot was 100 m^2. Each farmer was considered a single replication in the analysis. Farmers were provided with free test seeds and fertilizer, but they conducted all activities themselves. ICRISAT enumerators monitored fertilizer applications and harvest to ensure accuracy. Serious rainfall deficits in all our study villages reduced test yields substantially below levels in previous years. Annual rainfall totals were 60-75% of average in the Sudanian villages and 75-80% of average in the Guinean villages. In addition to the aggregate deficit, periodic droughts occurred in late June and the first half of July when the majority of tests were planted (causing seedling establishment problems), throughout August, and in early September during flowering.

Average yields of ICSV 1002 HV were 12-20% higher than local varieties at all fertilizer levels in the Boromo villages (Table 1). Due to high variability accentuated by drought conditions however, in no cases did tests of paired plots across sites within each fertilizer treatment identify significant varietal differences. ICSV 1002 HV showed marginal (9-12%) but nonsignificant yield superiority over local controls in Yako only, at moderately-high fertilizer doses. ICSV 1003 HV and ICSV 1004 HV yielded consistently lower than the locals at all fertilizer levels.

We examined the separate components of grain yield—plants ha^{-1}, panicles $plant^{-1}$, and grain mass $panicle^{-1}$ to measure varietal differences. The results show that the major limiting factor for each of the test varieties was low plant stand followed by low numbers of panicles $plant^{-1}$. In both the Sudanian and Northern Guinean test sites, plant stand at harvest for ICSV 1002 HV was 25% less than for the local varieties.

Plant stands were only 68% of the local control varieties for ICSV 1003 HV and 57% for ICSV 1004 HV. In both zones varietal differences in plant stand were significant at the 0.1% level of probability.

The number of panicles $plant^{-1}$ was severely reduced by drought in the Sudanian Yako villages. In the Guinean Boromo sites the overall

Table 1. Mean yields (kg ha^{-1}) for test and local varieties of white-grain sorghum at five levels of fertilizer application. Farmers' tests results from 100 m plots, Vako and Boromo study villages, Burkina Faso, 1984[1].

Fertilizer applied (kg ha^{-1})		Grain yields (kg ha^{-1})							
		Yako				Boromo			
N15:P23:K14	Urea	Local	ICSV 1002 HV	ICSV 1003 HV	Mean	Local	ICSV 1002 HV	ICSV 1004 HV	Mean
0	0	130	120	80	100	440	510	410	460
50	0	200	200	130	160	580	670	540	590
100	0	230	250	190	220	700	840	650	720
300	0	380	350	290	330	850	950	590	790
100	50	260	290	220	260	880	1010	690	850
Mean		240	230	180		680	790	580	
SE			±34		+87		+104		+ 155

1. The significance of differences in mean yields between each test variety and the paired local variety was tested using a one-tailed t-test of mean differences between matched pairs. The only significant difference was between the local variety and ICSV 1004 HV at 300 kg ha^{-1} N15:P23:K 14.

average was 29% plants without panicles. Spittle bug *(Poophilus costalis)* attacks, observed only on the test varieties, and poor head exertion resulted in a significantly lower ratio of panicles $plant^{-1}$ for the test compared to the local varieties in both zones.

Compensating for the low number of heads ha^{-1}, however, all test varieties had significantly greater grain mass $panicle^{-1}$. In Yako, the test varieties surpassed the local control variety by 38%, and in Boromo by 53%.

A review of average yields from farmers' tests in 1983 and 1984 shows that ICSV 1002 HV was in nearly all cases superior to the local varieties under low-fertility conditions when rainfall exceeded 600 mm, and under high-fertility conditions with rainfall as low as 450 mm. This reflects the generally wide adaptability of the variety. The low risk of yield failure under both low and high fertility reflected in yield distributions for 1983 and 1984 demonstrate considerable yield stability over a range of microenvironmental conditions. ICSV 1002 HV also responds well, probably better than local varieties, to improved soil tillage and fertility under farmers' management.

We identified a number of problems with ICSV 1002 HV in farmers' tests which, if eliminated, could result in substantially improved performance and adoption potential. These include: (1) poor head exertion under drought stress, (2) susceptibility to spittle bug, (3) only moderate resistance to *Striga* (as reflected in the number of *Striga* plants $hill^{-1}$), and (4) an overly-compact head which contributes to hemipteran infestation by various hemipteran head bugs, and grain quality problems. In view of the low seedling emergence and plant stand rates observed in 1984 (in contrast to 1983 results), seedling establishment under controlled low-tillage conditions will also be verified in further trials.

Determinants of Station-to-Farmer Yield Gap in West Africa

Farmers' tests since 1980 have shown that most elite varieties suffer a yield loss of between 40 and 60% when transferred from research station trials to farmer's fields, even when cultivated at similar levels of fertilizer application (ICRISAT

ICRISAT researchers and farmers discussing yield gaps in on-farm research in West Africa.

Annual Report 1983, p. 312). We conducted experiments in three sites during 1984 to measure the principal causes of the yield gap. Data on farmers' management obtained from farmers' tests and baseline surveys suggest that five factors were important: (1) plowing or direct seeding, (2) timing of fertilizer application, (3) presence of tied ridges, (4) planting arrangement, and (5) weeding frequency. We tested these five factors at two management levels-research station and farmer management in a 2^5 factorial design. The actual factors used are shown in Table 2 for the two management levels. ICSV 1002 HV was sown in all treatments, and 100 kg N14:P23:K15 ha^{-1} and 50 kg urea ha"[1] were applied throughout. The experiment was conducted at Kamboinse research station as well as in one village each in the Boromo and Yako zones. The experiment at Kamboinse failed completely due to extended early- and mid-season drought.

The five management factors accounted for 65% yield variation at the Boromo site and 90% at the Yako site. The largest and most significant main effects were for tied ridging that increased yields by 40% in Yako and by 75% in Boromo (Table 3). In Yako, significant main effects (P = 0.05) were also observed for deep plowing (40% yield increase) and timely weeding (20% yield increase). Plowing and tied ridging had a significant negative interaction effect on yields in Yako. A significant positive interaction was observed between plowing, weeding, and timing of fertilizer application in Yako. This indicates that thorough weed control is most important where early fertilizer application and enhanced

Table 2. Management factors used at two management levels in determining station-to-farmer yield gap, Burkina Faso, 1984.

Management factor	Management level: Station	Farm
Plowing	Deep plowing	Direct seeding or shallow scarification
Time of fertilizer application	NPK before seeding urea 30 days later.	NPK and urea at first weeding (approx. 30 DAS)[1]
Tied ridging	Yes	No
Planting arrangement	One plant $hill^{-1}$ 20 cm between hills 80 cm between rows	2 plants $hill^{-1}$ 60 cm between hills 80 cm between rows
Weeding frequency	As necessary for weed-free soil surface	1st weeding 30 DAS 2nd weeding 60 DAS

1, DAS = Days after sowing.

Table 3. Sorghum yields ($kg\ ha^{-1}$) from five management factors applied at levels corresponding to research station trials and farmers' tests, results of yield-gap trial (plot size 22 m^2), in two villages, Burkina Faso, 1984.

Management factors	Grain yields ($kg\ ha^{-1}$) Yako S[1]	Yako F[2]	Boromo S	Boromo F
Plowing	1034	744	1376	1029
Time of fertilizer application	881	897	1344	1061
Tied ridging	1030	748	1526*	879
Planting arrangement	931	847	1151	1254
Weeding frequency	969	809	1194	1211
Mean	890		1200	
SE	+39		+133	
Significant management factor interactions	Plowing x tied ridging (negative)** Plowing x weeding timing (positive)* Fertilizer application timing x plowing x weeding timing (negative)*		No interaction	

1. S = Research station.
2. F = Farmers' field.

soil moisture (due to land preparation) combine to increase weed infestation.

A comparison of several years' results from on-station trials and farmers' tests shows that the yield gap is less for local than for improved varieties. Since tied ridging and deep plowing are the major determinants of the yield gap, this reflects the fact that local varieties are generally better adapted to zero plowing but at the same time less responsive to improved tillage practices. On-station trials previously conducted by the SAFGRAD-supported soil water management program (ICRISAT Annual Report 1983, p.298) have also demonstrated significant response differences between local and improved varieties subjected to various soil-management treatments.

Neither tied ridging nor deep plowing are widely practiced by farmers for sorghum production in the Sudanian or Sahelian zones. With few exceptions, most farm-level evaluations of tied ridging have shown that major labor bottlenecks and poor yield responses for local varieties under on-farm fertility conditions constrain adoption. Inadequate animal health and nutrition, lack of manpower, conflict with timely sowing, and poor yield response of local varieties to plowing similarly inhibit the adoption of mechanized plowing. More responsive varieties, particularly those which have a somewhat shorter growth cycle and could relieve the labor constraint, could make both practices more economical. Conversely, these practices may be necessary complements to ensure the performance of new varieties in farmers' fields.

However, for broad adoption of sorghum varieties, especially true for farmers who lack the capital or manpower to introduce complementary soil management practices, sorghum varieties more tolerant to low-tillage management are essential. The continued selection and development of new varieties solely under conditions of deep plowing and tied ridging makes it impossible to screen for this trait. The systematic screening of varieties under low-tillage conditions could reduce the station-to-farmer yield gap by producing varieties better adapted to soil-management conditions likely to dominate in much of West Africa in the foreseeable future.

Effect of Phosphorus Fertilizer on Millet Yields and Farmers' Returns in Niger

Tests conducted in previous years (ICRISAT Annual Report 1982, pp.367-368 and 1983, p.315) had shown that while presently recommended improved cultivars had very little or no advantage over local varieties at low-input levels, fertilizer application increased yields of both local and improved cultivars significantly, and that it could be profitable to apply fertilizers. In order to better understand fertilizer response under farm conditions, tests in 1984 concentrated only on phosphate fertilizer response.

We used a randomized split-plot design (plot sizes 250 m^2) to test fertilizer response in trials managed jointly by researchers and farmers. Two sources of phosphorus, single super phosphate (SSP) and partially acidulated (50%) Niger Park W rock phosphate (PARP) were compared at four levels of P_2O_5 (0, 12, 24, and 36 kg ha^{-1}) using farmers' local varieties. We applied 30 kg N as calcium ammonium nitrate (CAN) in all treatments. The nitrogen was applied in two split doses, approximately 15 days after seedling emergence and 30 days later. The phosphorus was broadcast but not incorporated at the time of plot layout, 2-4 weeks before sowing.

The tests were conducted in about 30 farmers' fields in each of the four villages where baseline studies are being conducted. Fertilizer application, harvesting, and recording of test results was monitored by research technicians. Farmers sowed their own varieties and carried out all their usual cultural practices.

Each farmer had four 250 m^2 plots—the zero treatment, one level of SSP, the same level of PARP, and a different dose of either SSP or PARP. Thus, every treatment occurred 16 times in a 30-household village, except for the zero treatment which occurred 30 times.

Rainfall in all the study villages was substantially lower than the long-term average (Table 4).

Table 4. Annual rainfall (mm) in four villages in western Niger where farmers' tests were conducted in 1984.

Villages	Long term average	1982	1983	1984
Dallol Bosso	600			
Fabidji		NA[1]	410	369
Gobery		540	392	422
Zamanganda	400			
Sadeize Koira		240	361	215
Samari		NA	345	160

1. NA = not available.

While the southern villages (Fabidji and Gobery) received enough rainfall to allow crops to reach maturity and harvest, the rainfall in Sadeize Koira (only 60% of 1983 rainfall) and Samari, (only 46% of 1983 rainfall) was insufficient to allow a harvest, particularly as late rains in September fell too late to be of use to the millet crop. Thus the farmers' tests in these two villages produced no yield, as was the case with virtually all the farmers' fields.

Because of the drought situation millet grain yields were very low. Mean grain yields were 44-130% higher for all fertilized compared to nonfertilized treatments that received fertilizer except for the 12 kg P applied as PARP in Fabidji. But these increases were significant *(P* = 0.05) only at the 24-kg and 36-kg P levels except for the 36 kg P as PARP (Table 5). The high variation in yields within treatments, as indicated by the high standard deviations, showed that other factors had much effect on the yields.

We applied the partial budget analysis to examine the economics of fertilizer use under the conditions prevailing in 1984. Since the exploratory regression analysis had indicated the importance of sowing date, to be immediately after the first rain, and quantity of fertilizer in explaining yields, the farmers were divided into 16 groups based on these criteria with village location replacing rainfall. The characteristics of the groups are shown in Table 6. Since group 8 (late sowing with 36 kg phosphorus in Fabidji) contained only one valid case, it was not included in the analysis.

The results in Table 7 show that on the average, financial returns at farm site were positive for all groups and were highest at 24 units of phosphorus when the crop was sown on time (within 4 days of the first major rainfall). Late sowing resulted in substantial decreases in net

Table 5. Mean yields (kg ha-[1]) for local pearl millet varieties at four levels of phosphorus, farmers' tests results, western Niger, 1984.

Phosphorus (kg ha-')	Mean yields (kg ha-')							
	Fabidji				Gobery			
	PARP'		SSP[2]		PARP		SSP	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0	140	+65	140	+65	130	+100	130	84
12	140	118	210	122	190	118	190	±109
24	220*[3]	72	260*	123	200*	109	320*	148
36	210	122	230*	99	240*	139	290*	104
SE	±44		±25		±26		±68	

1. PARP = Partially-Acidulated Rock Phosphate.
2. SSP = Single Super Phosphate.
3. Probability level of significance of difference of mean yields between each level/source of fertilizer and the treatment using two-tailed t-tests is * = 0.05.

Table 6. Pearl millet grain yields (kg ha^{-1}), timeliness of planting, level of phosphorus, and grain/fertilizer ratios for different groups in two villages, western Niger, 1984.

Group	Number of plots	Mean	SD	L[1]	P[2]	M/P[3]
Fabidji						
1	17	155	64	T	0	
2	14	216	141	T	12	5.1
3	17	265	99	T	24	4.6
4	20	231	106	T	36	2.1
5	5	102	37	L	0	—
6	8	119	43	L	12	1.4
7	5	142	37	L	24	1.4
Gobery						
1	20	151	115	T	0	
2	16	208	98	T	12	4.7
3	23	265	138	T	24	4.7
4	21	288	135	T	36	3.8
5	8	65	61	L	0	—
6	9	118	74	L	12	4.4
7	5	172	80	L	24	4.4
8	7	188	40	L	36	3.4

1. T= Planting within 4 days of the first rain.
L = Planting more than 4 days after the first rain.
2. Nurtient basis (kg ha-')-
3. Kg millet grain per kg phosphorus applied.

revenue particularly in Fabidji, where total rainfall was lower than in Gobery. At unsubsidized world market prices of fertilizer, net returns were substantially reduced, but remained positive for all groups in the higher-rainfall village (Gobery). They were negative for late-sown crops in Fabidji, and at 36 kg phosphorus, even when sown on time.

We conclude that provided farmers sow their millet crop on time and there is sufficient rainfall to harvest a crop, phosphorus fertilizer application up to the 24-kg P ha^{-1} level is likely to be economical.

Contributions of Production Factors to the Returns from Improved Vertisol Technology

We used the data collected from the on-farm research site in Taddanpally village of Andhra Pradesh during 1981-82 in modeling representative farms to evaluate the adoption potential of the improved Vertisol technology (1CRISAT Annual Report 1983, p.315) and to measure the consequential changes in factor shares.

The whole-farm models show that the improved technology can be expected to be adopted on operated land of 75% small, and 90% large farms, and that it offers attractive rates of return on extra costs. The improved technology raises gross revenue substantially on both farm types (Table 8). As a result, absolute values of returns on almost all factors including human labor rise sharply.

The factor share of capital rises with the improved technology mainly because of the introduction of the wheeled tool carrier (WTC) and increased fertilizer use. For both farm types, 75% of the increase in returns is due to increased fertilizer use. The factor share of bullock labor declines by about 10% because the WTC

Table 7. Analysis of returns to phosphorus fertilizer use in pearl millet production in western Niger in 1984, using domestic market prices for grain and straw, and subsidized fertilizer prices (F CFA ha^{-1})[1].

Farm group	Gross revenue (000 CFA)	Total cost (000 CFA)	Returns: Total (000 CFA)	Net[2] (000 CFA)	R/P[3]
Fabidji					
1	26	3.3	23	—	—
2	34	5.7	28	5.5	3.3
3	41	8.1	33	10.1	3.1
4	37	10.5	27	4.1	1.6
5	18	3.3	15	—	—
6	21	5.7	15	0.5	1.2
7	23	8.1	15	0.5	1.1
Gobery					
1	22	3.3	19	—	—
2	30	5.7	25	5.5	3.3
3	39	8.1	31	11.8	3.5
4	42	10.5	32	12.6	2.8
5	11	3.3	8	—	—
6	18	5.7	13	5.1	3.1
7	27	8.1	19	11.3	3.3
8	29	10.5	19	11.0	2.5

1. Prices used are the average of prices paid by farmers in the study villages i.e., 130 F CFA kg^{-1} for millet grain, 8 F CFA kg^{-1} for millet straw, 109 F CFA kg^{-1} for N, and 200 F CFA kg^{-1} for P.
2. Change due to fertilizer use.
3. Net returns (F CFA) FF-' invested in phosphate fertilizer.

Table 8. Impact of improved technology on returns to factors (results from whole-farm modeling, Taddanpally, India).

Factors	Small farm (1.53 ha): Traditional technology (Rs)	(%)	Improved technology (Rs)	(%)	Large farm (6.88 ha): Traditional technology (Rs)	(%)	Improved technology (Rs)	(%)
Gross revenue	2870	100	6565	100	16930	100	30120	100
Land	794	27.7	1057	16.1	3570	21.1	4550	15.1
Labor	576	20.1	932	14.2	4120	24.3	5327	17.7
Capital								
Non-land assets	192	6.7	307	4.7	2535	15.0	2965	9.8
Irrigation infrastructure	0	0	0	0	1962	11.6	1962	6.5
Wheeled tool carrier	0	0	115	1.8	0	0	430	1.4
Variable expenditure	797	27.8	1561	23.8	5434	32.1	8445	28.0
Fertilizer	37	1.3	710	10.8	900	5.3	3600	12.0
Bullock	193	6.7	173	2.6	1385	8.2	1213	4.0
Total capital	989	34.5	1868	28.5	7970	47.1	11410	37.9
Residual	511	17.8	2708	41.2	1271	7.5	8833	29.3

increases bullock labor efficiency by a factor of 2.15 over traditional implements. Although not accounted for by the model, the overall demand for bullock labor may increase due to the derived demand for transportation because of additional inputs and outputs.

With improved technology, the factor shares of almost all factors except fertilizer decline substantially, indicating factor-saving technological change.

Labor's share in increased revenue comes second to fertilizer. The degree of increased revenue due to labor (9%) compares favorably with estimates of 2 to 5% obtained for the high-yielding varieties of wheat and rice. Labor produces a higher proportion of increased gross revenue than land, which indicates that the improved technology has potential to augment land and labor use.

The impact of the improved technology on income distribution can be viewed by linking the functional distribution of income for factors of production with the personal distribution of income for different socioeconomic groups. With the improved technology, small farms that comprise 76% of the sample, receive 36% of the total net income when they only have access to local technology. With the introduction of improved technology their income share rises to 43%, while the income share that goes to large farms falls from 64 to 57%.

Credit Needs of Vertisol Technology

Cash on hand to meet variable crop expenses is one very important factor that may limit the extent of transfer of Vertisol technology in the credit-starved economy of dryland regions of India. Our surveys at Taddanpally and Begumganj show that short-term cash requirements for the improved technology are twice as much as for local technology. The additional requirement is in the range of Rs 600 to 1300 ha^{-1} and varies from region to region.

In the Taddanpally/Sultanpur area, the crop loan should be around Rs 1000 ha^{-1} a^{-1}, ranging from Rs 400 for postrainy season sole sorghum to Rs 1550 for sequentially cropped maize-chickpea. Similar requirements were found for the Farhatabad area of Karnataka, where the loan should amount to Rs. 1050 ha^{-1} a^{-1} ranging from Rs 600 for postrainy season sole sorghum to Rs 1450 for intercropped groundnut/pigeonpea. For the Begumganj area an average amount of Rs 2050 ha^{-1} a^{-1} would be required, ranging from Rs 1200 for intercropped sorghum/ pigeonpea to Rs 3000 for soybean followed sequentially by wheat or chickpea. These figures are very sensitive to changes in input prices, therefore any designed scale of finance has to be sufficiently flexible to adapt to local conditions and current prices.

We employed whole-farm models to evaluate the adoption potential for the improved technology and the corresponding credit needs. The results (Table 9) show how credit may affect adoption of the improved technology. Without institutional credit availability, the adoption level is nil on small farms, 17% on medium farms, and 16% on large farms. When credit of Rs 1200 ha^{-1} to small farms, Rs 940 ha^{-1} to medium farms, and Rs 980 ha^{-1} to large farms is made available, the adoption potential for the improved technology goes up to 91, 77, and 80% on these farms. For adoption on about 75% of the land, credit levels of about Rs 600 to Rs 700 ha^{-1} would be required for farms of all sizes. In comparison, the credit supply at present in India is on average Rs 324 ha^{-1} i.e., considerably below the required levels of institutional credit. The figure of Rs. 700 ha^{-1} adopted by the Andhra Pradesh Department of Agriculture to finance Taddanpally watershed farmers is below the level required for maximum adoption, but it would seem to be sufficient for adoption on approximately 75% of the land.

Prices and Costs of the Wheeled Tool Carrier

The prices quoted for the WTC vary between manufacturers and with the number of implements supplied with it. When a WTC is purchased with a full set of implements, its price varies between Rs 12 500 and Rs 15 000. However, not all implements are necessary to practice the

Table 9. Potential demand for and repayment of institutional credit with improved and traditional technologies, Taddanpally, 1981/82.

	With deep Vertisol technology				With traditional technology	
Farm size	Credit level (Rs ha^{-1})	Credit utilized[1] (Rs $farm^{-1}$)	Shadow price of credit[2] (Rs)	Improved technology adoption (%)	Credit utilized (Rs $farm^{-1}$)	Shadow price of credit (Rs)
Small	0	IP	IF	IF	IF	IF
	150	200	3.42	30	IF	IF
	300	500	2.53	39	IF	IF
	700	1100	0.97	90	1100	0.23
	No limit	1840	0	91	1360	0
Medium	0	0	4.26	17	0	4.69
	150	500	3.82	33	500	0.87
	300	1000	2.55	54	1000	0.26
	700	2300	0.65	75	1780	0
	No limit	3130	0	77	1780	0
Large	0	0	4.14	16	0	2.97
	150	1000	3.59	33	1000	1.17
	300	2100	2.83	55	2100	0.64
	700	4800	0.71	91	3940	0
	No limit	6760	0	80	3940	0

1. Institutional credit requirement by optimal programming solution.
2. Shadow price = the calculation ofnotional or imputed prices where they are not obtained from markets.
3. IF = infeasible programming solution and, hence, infeasible farm business i.e., the farmer would be in debt.

improved Vertisol technology. Only the following implements are necesssary: 2 moldboard plows, 2 ridgers, 5 duckfoot sweeps, 4 blade harrows without shanks, a steerable tool bar, a link chain, 7 clamps, one yoke, a cart frame, and a manual seeder. With these implements, the lowest prices listed by manufacturers were Rs 8510 for an assembled Tropicultor and Rs 9010 for an assembled Nikart (Table 10), Since WTCs are composed of several modules, buyers can purchase them from the manufacturer who lists the lowest price for a particular module. Calculated on the basis of the lowest listed prices for individual modules, the price for a Tropicultor is reduced to Rs 7995 and for a Nikart to Rs 8145.

Fully assembled sets of WTCs and modules are presently produced only by a small number of manufacturers who may, in the short run, ask for higher than competitive prices. In order to arrive at a competitive price estimate for WTCs produced by a manufacturer, two estimates were calculated. First, we obtained market prices for the elements of WTCs e.g., raw materials, nuts, bolts, chains, etc. These prices, when multiplied by the quantities of material contained in WTCs, plus labor costs and 20% overheads, resulted in an estimated cost of Rs 7405 for a Tropicultor and Rs 7765 for a Nikart.

Alternatively, we regressed market prices for widely traded modules that are similar to those used in WTCs, e.g., plows, ridger, seed drills, etc., on their weight, and from these regressions we estimated the prices for WTC modules. Estimated in this way, we expect prices for the WTC

Table 10. Summary of price estimations (Rs) for wheeled tool carriers[1].

With necessary implements	Minimum listed price	Minimum module price	Estimated price from the cost analysis	Estimated price from price-weight relationships
Tropicultor	8510	7995 (6.0)[2]	7405(13.0)	6825(19.8)
Nikart	9010	8145(9.6)	7765(13.8)	6590 (26.9)

1. These estimates were obtained on the basis of price quotations in November 1983 and price observations in February 1984.
2. Figures in parentheses are percentage price reductions from minimum listed price.

with necessary implements of Rs 6828 for a Tropicultor and Rs 6590 for a Nikart.

Production and Sales

At present there are five small-scale manufacturers of the WTC in India who began production between 1978 and 1983. Of the 78% WTCs sold as of March 1984, about three quarters have been purchased by government institutions mainly for subsidized sale to farmers (46%) and for demonstration (26%); the rest were used for testing and evaluation (see Table 11). The subsidy for WTCs may be as high as 80%. Nongovernment institutions have purchased about 6% of the WTCs sold and use them mainly for testing and evaluation. Since 17% of the WTCs were exported or went to unidentified buyers, the proportion of WTCs known to have been bought directly by individuals at unsubsidized prices amounts to only 3%. This small number of free transactions makes assessment of demand and supply for WTCs only on the basis of their market prices and quantities traded unreliable. In this situation, it is appropriate to estimate minimum costs of production as an indicator for supply and to identify important economic considerations affecting demand for WTCs.

Table 11, Buyers of wheeled tool carriers (WTCs) as of March 1984.

Buyer	Machines sold	Percentage of total
Farmers	24	3
Non-governmentinstitutions for testing and evaluation	47	6
Government bodies:		
total	581	74
for subsequent subsidized sale to farmers	361	46
for demonstration	204	26
for testing and evaluation	16	2
Foreign	24	3
Uncategorized	110	14
Total	786	100

Future demand for WTCs is likely to remain low at present listed prices and estimated reduced prices. In a survey of farmers in Madhya Pradesh in 1983, where the improved Vertisol technology appears to be highly suitable, farmers who did not own WTCs indicated that they would, on average, be willing to pay only a maximum price of Rs 3300 for a WTC.

Resource Management

Land Use, Tenure, and Inheritance in West Africa

One objective of our Village-Level Studies (VLS) has been to identify the principal trends in

An ICRISAT study village in the harsh environment of the Sahelian zone, Niger.

the local farming systems and their implications for technological change. Through retrospective interviews, verified by a comparison of past census results and with the aid of aerial photographs, we found that population densities are rising in all our study villages (Table 12). In response to this trend, farming systems are moving toward greater intensification while at the same time farmers are extending cultivation to more marginal lands. Studies of land use suggested that in villages where land is in short supply, proportionately more of the cereal crop is produced on the less fertile soils. This means that as the village population grows, the self sufficiency of the farmers will depend more and more on the capacity of the upland soils to sustain cultivation.

Two ICRISAT study villages in the same agroclimatic zone in Burkina Faso but with contrasting population densities provide a valuable contrast from which one can infer the change in agriculture that might be expected to occur as population density increases. Koho (population 1145) and Sayero (population 932) are both located in the northern Guinean Zone with an average annual rainfall of just under 1000 mm.

The limits of the village territories have not been extended in several decades. Both villages have lost land due to the creation of national forests and new settlements which sprang up following the building of paved roads and the laying of railway lines. This was especially true in Koho, which since 1960 has lost about half of its original territory. There were about 1320 ha of land available in Koho in 1982, or about 1.15 ha person^{-1}. Of this, about 590 ha, or 45%, was cultivated. This amounts to 0.52 ha person^{-1}. There is about 0.5 ha of virgin gallery forest remaining. Some 715 ha, or 54% of the land, was found to be lying fallow.

Sayero, located only 17 km from Koho by road, presents a very different picture. The village territory consists of about 3850 ha or over 4 ha person^{-1}. Only 510 ha, about 13% of the village land, was cultivated, which means that on an average there are 0.55 ha person^{-1}, which is

Table 12. Changes in population densities in ICRISAT study villages, Burkina Faso, 1975-1983.

Village	Ecological zone	Village territory (ha)[1]	Population 1975[2]	Population 1983[3]	Population density 1975	Population density 1983	Regional population density in 1975 (habitants km^{-2})
Oure	Sahelian	1875					25
Silgey		1552	481	636	31	41	
Kolbila	Sudanian	1946	905	1321	47	68	60
Ouonon[4]		-	868	1224			
Koho	Guinean	1316	962	1145	73	87	30
Sayero		3845	867	931	23	24	

1. Calculated from maps made from aerial photographs taken during December 1981 and subsequent fieldwork conducted in the villages.
2. Official census data.
3. ICRISAT survey data.
4. Aerial photographs were insufficiently clear to allow mapping of Ouonon.

very similar to what was found in Koho. Over 3000 ha, or 78% of the land was lying fallow. There were 180 ha (4%) of virgin gallery forest remaining.

Average farm size was approximately 6 ha in both villages. Thus farm size in Koho does not seem to have been reduced with increased crowding. What we do find, however, is a change in the proportions of richer river valley land cultivated. In Sayero about 13% of farmland is located in rich lowlands, whereas in Koho only 3% of the farmland is of this type. This is not apparently the result of a significant difference in the distribution of these soil types in their respective territories, for the aerial photographs indicate that they both have similar amounts of lowland- 5.7% of all land in Koho and 7.7% in Sayero. It is probably because of crowding that Koho farmers are farming relatively more land higher up where the soils are poorer.

The land tenure systems in operation in Koho and Sayero clearly reflect the differences in population pressure. In Koho the cultivation rights to particular pieces of ground, even when the land is fallow, are generally heritable. Sayero on the other hand, still has a rather classic long fallow usufruct system for bush fields. All such fields revert to the whole community, whose interests are represented by the village chief. The land then is cleared and cultivated afresh after a period of 20-30 years of fallow, but not necessarily by the same person, family, or even by members of the same lineages who last used it. Heritable cultivation rights are confined to the more permanently cultivated lands immediately surrounding the village.

The effect of rising population density on security of tenure was ambiguous, depending on whether land was inherited, borrowed, or cleared from unclaimed bush. In both villages, for fields continuously cultivated around habitations, cultivation rights were generally retained by individuals or by their families. In Koho this was even true of bush fields, many of which were passed down from father to son even throughout a long period of fallow. The land could not be allocated to someone else without prior consultation with the farmer who had last used the land. In Sayero the fallow land was sufficiently abundant and the length of fallow sufficiently long (25-30 years), so that old fields are often recultivated by persons other than the descendants of those who had cultivated them last.

In Koho where land is becoming scarce, leasing or lending for more than several years has become extremely rare. This is because having once lent out their land, owners may have great difficulty in reclaiming it. Such long-term leasing or borrowing arrangements in Koho, when practiced, provide substantial security of tenure to borrowers to the extent that cultivation rights can be passed down from father to son despite the fact that the latter still acknowledged the field as leased land. On the other hand, the more recently leased land is held far less securely. Tenants admitted that they could be asked to give up use of the land and in some cases there appears to have been a time limit on the lease arranged from the beginning. It is possible that the more inflexible and insecure conditions for land borrowed on such short-term arrangements may be a disincentive to better management.

For example, an analysis of technology and fertilizer use on borrowed fields in Koho (which represented a small fraction of total cultivated land) indicated that only 30% of the recently borrowed fields were plowed, and only 20% of them were treated with fertilizer, while on inherited borrowed fields, 50% of the fields were plowed and 60% of them received fertilizer.

Traditional Management of Soil Fertility in West Africa

In the crop-growing areas of the West African SAT, mounting population pressure has resulted in traditional long bush-fallow systems giving way to more intensive short grass-fallows and continuous cultivation systems. In areas where population pressure is highest, such continuous low-input cropping has led to severe soil degradation problems which have measurably reduced the soils' production potential. Farmers are adopting various practices to maintain soil fertility.

To examine traditional methods of soil-fertility maintenance and their effects on long-term soil quality, we made a study within the ICRISAT village study program. The study combined intensive field surveys and laboratory analysis of soil samples taken from farmers' fields. Analysis completed to date has concentrated on data from Nonghin, one of the two study villages in the Manga region (1200 mm long-term average annual rainfall). Population density in Nonghin at 40 persons km^{-2} is moderately high.

Management Rings

Analysis of six years of retrospective data from 185 farmers' fields found that fields could be grouped into five elementary soil-fertility management sub-sets according to their (1) cropping sequence, (2) fertilizer application sequence, (3) soil preparation sequence, and (4) conservation methods. These sub-sets in turn are closely correlated with distance from habitation points and, for simplification, could be further grouped into three concentric management rings emanating from each household (Table 13).

Cultivation is quasi-permanent in the first and second rings, but follows a fallow rotation in the third ring. Fertility in the first ring is maintained by application of large quantities of organic matter, complemented by anti-erosion dikes to reduce runoff loss. Near-continuous cultivation is maintained in the second ring through moderate doses of manure and chemical fertilizers, low-level cowpea intercropping, and the inclusion of groundnuts in rotation. Cropping is least intensive in the third ring where fertility is maintained by frequent fallowing and by cultivating legumes as intercrops and in rotation.

The value of production ha^{-1} and labor h^{-1} is highest in the inner rings, reflecting the combined effects of manure use and cropping pattern. Regression analysis shows that at the margin, the production response to manure is large and significant only in the outer ring. This means that important aggregate production gains could be achieved through a reallocation of manure to fields more distant from dwellings. This may be explained simply by transport costs of manure; but the prevailing land tenure system may leave the individual owner uncertain about his access to the same land in future years and therefore restrict his investment on this land.

Table 13. Production characteristics of soil fertility management rings on farmers' fields, Nonghin, Burkina Faso, 1981.

Characteristics	Management ring 1	2	3
General			
Distance from household (m)	0-40	40-410	410-3050
Total cultivated area (%)	3	23	74
Major crops	Maize Red sorghum	Red sorghum White sorghum Cowpea Groundnut	Millet White sorghum Cowpea Groundnut
Management practices			
Years of fallow in last 25 years	2	3	11
Manure rate (kg ha^{-1})	8900	1010	35
Chemical fertilizer rate (kg ha^{-1})	9	11	6
Fields with permanent anti-erosion devices (%)	94	16	11
Density of cowpea intercrop (plants ha^{-1})	20	1250	3980
Fields planted to groundnut in past 6 years (%)	0	35	40
Total plant density (plants ha^{-1})	28 400	35 700	44 200
Labor time (h ha^{-1})	620	600	520
Production			
Grain yield (kg ha^{-1})	2110	1510	490
Value of output ha^{-1} (F CFA ha^{-1})	170 000	61000	27 000
Value of output labor h^{-1} (F CFA h^{-1})	270	100	50
Elasticity of grain production to manure use	0.11	0.05	0.25

Management Effects on Soil Quality

To infer the dynamic effects of management practices on soil fertility, we statistically tested five measures of soil quality, contrasting the values obtained from fallow fields with those from each interior management ring. To capture the effect of the duration of cultivation on the chemical fertility inside each management ring, the soil samples from each ring were stratified by soil type and by field-age intervals for statistical analysis. The results of the inter-ring comparisons showed that the chemical fertility of upland soils actually increases with more intensive cultivation as practiced by farmers. All fertility measures improved soils compared to those in fallow fields, with the largest and most significant increases observed on the more intensively cultivated center area. The age analysis for upland soils also showed an unambiguous improvement in chemical fertility with longer periods of cultivation on gravelly soils inside the intermediate rings and on sandy soils inside the inner ring. No clear trends were observed in the age analysis on other soil types and for other management rings.

In contrast to the net improvement of the chemical status of soils with more intensive cultivation, there was evidence from the analysis, confirmed by farmers' comments, that the textural composition of certain soils is degraded through an increase in cultivation intensity, leading to a decline in water-holding capacity. Farmers explained that due to increased erosion caused by clearing and subsequent tillage, the most common sandy soil of their village had evolved over time to a sandy gravelly soil type. Laboratory analysis confirmed that the latter soil type had a lower water-holding capacity and may well have evolved from the former. Analysis of field ages also confirmed that the fields located on the sandy gravelly soil had been cultivated for a substantially longer period of time and under a greater average intensity of land use than those fields located on the sandy soil type.

These results question the common belief that current low-input farming practices tend to deplete the natural chemical fertility base of soils. Through the use of organic and inorganic fertilizers and by growing legumes in rotation or as intercrops, farmers may be able to maintain or improve the fertility of soils as fallow periods are shortened. However, intensified cultivation may induce the less reversible problem of physical degradation in soils. This emphasizes the need to develop appropriate methods to reduce top-soil loss as an immediate priority for research and extension for areas of increasing farming intensity.

African trainees watching women demonstrate local hand-weeding techniques during a visit to an ICRISAT study village in India.

Resources and Productivity of Traditional Farms in SAT India

We generated comparable data on resources and productivity for all the Indian villages under study by the Economics Program (ICRISAT Annual Report 1982, p. 315). Average operational holdings range from nearly 3 ha in the Gujarat villages to about 6 ha in the Maharashtra villages. In these villages, during 1980-82 average household incomes per capita were found to range from Rs 800 to Rs 1200. Incomes were lowest in the Madhya Pradesh villages where high rainfall (1300 mm) and deep Vertisols have led to traditional farming systems of fallowing during the rainy season and crop production on residual moisture in the postrainy season. Highest incomes are generated in the Maharashtra villages where assured rainfall (800 mm) and shallow- to medium-deep Vertisols permit farming systems of intensive rainy season cropping with a high proportion of cotton as a commercial crop.

The unusually high yields of pearl millet in the Gujarat villages are explained by the fact that farmers here are growing pearl millet as an irrigated crop under high-input management (Table 14).

Common Property Resources

The results on contribution of common property resources (CPRs), such as community pastures, forests, wastelands, ponds, watershed drainages, etc. to local farming systems reported earlier (ICRISAT Annual Report 1983, p.335) for a few areas were further confirmed by additional data from more areas. Labor and small-farm households relied much more on CPRs than large-farm households. Generally, in areas with higher population density the proportion of total land area used as CPRs is low. Over the last 30 years the total CPR area has substantially decreased. In all the areas studied, we found that CPRs have been privatized on an extensive scale. An important feature of privatization of CPRs is

Table 14. Features of traditional farming in study villages from four states in SAT-India, 1980-82[1].

	Village means				
Particulars	Aurepalle and Dokur (Andhra Pradesh)	Shirapur and Kalman (Maharashtra)	Kanzara and Kinkheda (Maharashtra)	Rampur Kalan and Papda (Madhya Pradesh)	Boriya and Rampura (Gujarat)
Soil type	Shallow and medium Alfisols	Medium and deep Vertisols	Shallow to medium Vertisols	Medium to deep Vertisols	Entisols
Normal annual rainfall (mm)	713	691	817	1330	802
Average number of household members	5.96	6.55	5.82	6.0	5.26
Average size of operational holding (ha)	5.08	1.43	5.77	5.14	2.89
Number of bullocks/10 ha of operated land	2.16	1.01	2.27	3.40	2.94
Input use (Rs ha^{-1})					
Manure	65	11	32	20	68
Fertilizer	83	15	119	12	131
Pesticides	8	1	23	116	
Land productivity (Rs ha^{-1})					
Gross return	3109	2431	3905	2441	4383
Net return	1904	1795	2617	1777	1586
Income (Rs capita^{-1})	1006	1005	1156	796	1042
Assets (Rs '000/household)	24.7	26.5	24.5	33.8	39.4
Cropping system[2]					
Intercropping (%)	49	45	81	33	45
HYV (%)	34	3	17	—	57
Irrigation (%)	50	23	22	34	3
Postrainy cropping (%)	20	76	4	82	16
Yield (kg ha-')					
Sorghum	278	455	956	204	421
Pearl millet	468	—	—	—	1478
Pigeonpea	138	225	—	243	247
Chickpea	328	339	389	441	329
Groundnut	986	881	715	—	804
Other major crops	224 (Castor)	238 (Sunflower)	804 (Cotton)	530 (Soybean)	490 (Castor)

1. Results from 30 sampled farming households in each village. 2. Percentages of total cropped area.

that in most cases the CPR lands went not only to the landless but also to those who already had a sufficient amount of land and were not originally intended as recipients. In some Rajasthan and Gujarat villages nearly 60% of CPR lands have been acquired by farmers whose land holdings exceeded 10 ha.

CPRs not only declined in area, but were also degraded in terms of physical productivity. Marked changes in the composition of the vegetative cover and a corresponding decline in the yield of physical produce was reported in all the areas studied. This degradation is the consequence of a slackening in the enforcement of traditional measures to regulate CPR use. Such regulations were formerly strictly enforced under Jagirdari/Zamindari systems where feudal landlords derived income from imposition of CPR-usage regulations. CPRs today are neither protected nor maintained through contribution from the users. Now entry taxes are not levied from users, thus making the CPRs more freely accessible.

We note several consequences of this decline in area and productivity of CPRs.

- CPRs are insufficient to offer full sustenance to the livestock dependent on them, and therefore large and medium farmers are supplementing their fodder base by providing stall feeding and private grazing to their animals.

- Animals belonging to the poor that depend largely on CPRs, are considerably inferior in health and productivity compared to animals maintained by private resources. Associated with this are lower conception rates, higher rates of miscarriage, and shorter lactation periods of milch stock sustained on CPRs.

- The decline in area and productivity of CPRs has led to increased reliance on farming systems based on private resources, the implications of which are an increasing need to adopt farming systems that provide more fodder and allow time for intensive animal care.

- Those small farmers who are finding it difficult under these conditions to maintain milch animals or bullocks will be forced to operate without their own animals, a fact which has several implications in terms of declining input supplies from livestock for crops.

Behavioral Studies

Credit Markets in Rural South India

We studied rural credit markets to understand the market structure and the operation of credit institutions in SAT villages, and to quantify the role of credit as a potential constraint to adoption of agricultural technologies. The study is based on data over 5 cropping years (1976-77 to 1980-81) in three study villages—Shirapur, District Sholapur, and Kanzara, District Akola, Maharashtra; and Aurepalle, District Mahbubnagar, Andhra Pradesh.

Credit Sources

Important sources of credit are formal institutions such as cooperative societies, land development and commercial banks and government agencies, and private lenders such as friends, relatives, and private moneylenders. In both Maharashtra villages cooperative societies are the most important source of credit, serving 65% of the households (Table 15). The land development bank ranks second in Kanzara and Aurepalle. In Aurepalle, Andhra Pradesh, a private moneylending system is still the major source of credit, whereas in Shirapur and Kanzara, Maharashtra, law has made private moneylending more difficult and it has thus sharply declined in importance.

Kanzara has the highest proportion of institutional credit (94%) followed by Shirapur (66%), and Aurepalle (47%) (Table 16).

Household groups at all levels in the three villages except labor households in Kanzara have access to credit and more than 85% of the households have taken loans. Total volume of borrowing per household in the three villages ranged from about Rs 1900 to Rs 4300. The large farmers' share in total institutional credit was

Table 15. Sources and volume of credit by credit agencies in three Indian villages, 1979/80.

Credit source		Shirapur	Kanzara	Aurepalle
Cooperative society	% share of total credit	47	46	1[1]
	% of beneficiaries	66	83	3
	Average credit per borrower (Rs)	1352	1831	400
Land development bank	% share of total credit	9	34	38
	% of beneficiaries	11	28	11
	Average credit per borrower (Rs)	1625	4101	15 500
Commercial bank	% share of total credit	8	11	2
	% of beneficiaries	5	7	3
	Average credit per borrower (Rs)	3000	5500	3600
Government agencies	% share of total credit	2	2	7
	% of beneficiaries	11	10	3
	Average credit per borrower (Rs)	382	800	11 000
Friends and relatives	% share of total credit	19	3	1
	% of beneficiaries	68	24	18
	Average credit per borrower (Rs)	537	343	207
Private moneylender	% share of total credit	15	4	52
	% of beneficiaries	24	28	95
	Average credit per borrower (Rs)	1182	433	2336
Beneficiaries as % of total households		95	73	95

1. % share of cooperative society in total credit is only 0.25%.

44% in Sholapur, 68% in Akola, and 74% in Mahbubnagar. Households possessing assets up to Rs 30000 represented 50 to 70% of sample households in the three villages and their share in total credit ranged between 22 to 37%. Households having assets of more than Rs 80000 represented only a little over 12% of households but their share of total credit ranged between 27 and 53%.

Credit Terms and Use

Analysis of the term structure and purpose of borrowings reveals the impact of agroclimatic factors on credit markets in the three ecologically-different regions. In drought-prone areas represented by Shirapur, where farmers have limited long-term investment alternatives, short-term credit dominates total borrowing, and credit is largely used to purchase livestock or for current consumption. In the other two villages, a higher proportion of long and medium-term borrowing was found, and the money was used mostly for long-term investments such as minor irrigation (Aurepalle) and land development (Kanzara).

There are considerable interfarm differences in credit use. Most of the landless laborers and small farmers often borrowed to meet current consumption needs (Table 17) rather than for long-term investment. Often borrowings and repayments by landless laborers were informally linked to their ability to supply cheap labor to the large farmers during the crop season.

In the three villages studied, about 40 to 60% of private credit is utilized for consumption.

Table 16. Access to credit by different farm-size groups in three Indian villages, 1979/80.

Village farm-size groups	Average credit per borrower household (Rs)	Share of each group in total borrowing (%)	Households having access to both institutional and private sources (%)	Households having access to institutional credit (%)	Households having access to private credit (%)	Share of institutional credit in total credit (%)
Shirapur[1]						
Labor households	862	9	100	75	87	75
Small farms	1630	16	87	50	75	38
Medium farms	2112	35	92	69	77	68
Large farms	2614	40	100	82	64	73
Total	1906	100	95	70	75	66
Kanzara[2]						
Labor households	140	1	12	0	12	0
Small farms	1385	17	80	73	33	95
Medium farms	1773	16	100	100	78	82
Large farms	9044	66	87	87	12	97
Total	3311	100	72	67	35	94
Aurepalle[3]						
Labor households	652	2	100	0	100	0
Small farms	1999	17	93	7	93	52
Medium farms	3750	21	100	11	100	15
Large farms	9756	60	91	36	82	59
Total	4278	100	95	15	93	47

1. Shirapur village, Sholapur District, Maharashtra State.
2. Kanzara village, Akola District, Maharashtra State.
3. Aurepalle village, Mahbubnagar District, Andhra Pradesh State.

Table 17. Percentage distribution of credit according to purpose in three Indian villages, 1979/80.

Purpose	Shirapur				Kanzara				Aurepalle			
	Labor house-holds	Small farms	Medium farms	Large farms	Labor house-holds	Small farms	Medium farms	Large farms	Labor house-holds	Small farms	Medium farms	Large farms
Agricultural inputs[1]	0	10	9	24	0	30	79	57	0	1	7	7
Livestock	75	26	7	23	0	0	0	0	0	13	0	2
Assets[2]	9	0	27	26	0	66	10	41	0	60	83	66
Ceremonies and marriages	11	11	11	11	71	0	4	0	65	11	7	24
Consumption[3]	5	27	19	11	29	4	7	2	24	14	3	1
Others[4]	0	26	27	5	0	0	0	0	11	1	0	0
Total credit (Rs)	6895	11 410	25 350	28 760	140	16 620	15 954	63 305	3260	27 986	33 750	77 556

1. Agricultural inputs: includes current inputs for production such as seed, fertilizer, pesticides, etc.
2. Assets: includes purchase of land, electric motors, oil engines, and credit for digging wells.
3. Consumption and domestic: includes credit used for consumption, hospitalization, education, etc.
4. Others: includes credit used for business, repayments of old debts, etc.

Similarly, institutional credit is often used for current consumption.

Default in Repayment

In contrast to institutional credit where repayment periods are explicitly fixed, no such terms are normally specified for private credit. Defaulting is therefore a feature mainly of institutional credit. In Kanzara and Shirapur, where institutional credit accounts for more than 65% of the total credit, the percentage of defaulting borrowers is higher (57 to 59%) compared to Aurepalle (17%). In Shirapur, overdues account for 96% of the institutional credit with an average overdue of Rs 1854 per defaulter. In Kanzara, overdues account for 67% of the total credit of defaulters with an average overdue of Rs 2990 per defaulter. In Aurepalle overdues of the defaulters constitute only 25% of the total institutional credit. In both Shirapur and Kanzara, the share of the cooperative society in total credit is more than 45% and its share in total overdue credit is 60 to 70%.

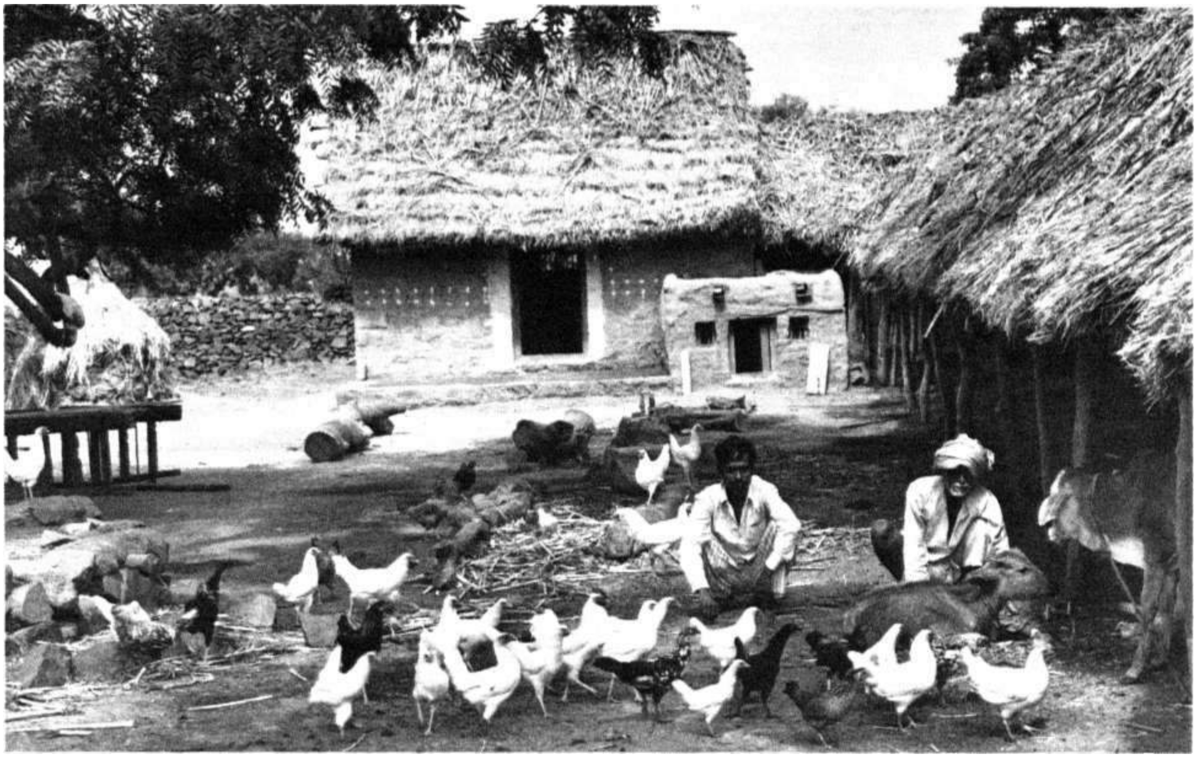
Borrowers' Characteristics

We analyzed the determinants of interhousehold differences in credit demand by regressing the total volume of credit on personal characteristics of household heads and resource-endowment of households. Regression results measure the extent to which institutional credit is concentrated in the better-endowed households with better educated, older household heads, larger families, and larger farms.

The variation across households in the use of credit from the private market was less well explained by these variables. Generally, household heads who relied more heavily on private credit were those who farmed more and better irrigated land, were less educated, and had fewer livestock.

Credit demand tends to increase at a decreasing rate with land area up to about 9 ha of operational holding. The relationships are quite similar for institutional and private credit.

While institutional credit decreases with assets



ICRISAT studies of the credit market in Indian villages showed that institutional credit is concentrated in the better-endowed households with better-educated, older household heads, larger families, and larger farms.

of up to Rs 26000, additional assets are associated with more credit demand. Private credit increases with higher assets throughout its range.

Households with higher assets tend to have lower repayment performance. Households with larger families and more dependents were more prone to default. From our study we could not identify the impact of house-head gender on borrowing behavior, but females appear to have a somewhat better repayment record than males.

Nutritional Focus of ICRISAT Research

We reviewed ICRISAT's research approach and priorities as part of a study to highlight the nutritional focus of research by the Consultative Group on International Agricultural Research (CGIAR) centers. The review indicated that ICRISAT's research attempts to improve the nutritional status of people, more by increasing the availability of food than by improving its nutritional quality. Accordingly, nutrition quality improvement (primarily improvement of protein quality), constitutes the principal objective of only 8-10% of the research projects on various mandate crops. About 34 to 75% of research projects covering different mandate crops are primarily directed to study yield reducers (drought, disease, pest, insect, etc.) (Table 18).

In-Service Training Program on Problem Identification and Technology Evaluation

A 5-week in-service training program was held for economists participating in interdisciplinary farming systems research in the SAT. The seven participants came from Bangladesh, Burkina Faso, Indonesia, Kenya, Mali, Nigeria, and Sri

Table 18. Percentage distribution of ICRISAT's research projects on different crops by major objectives (1975-1982).

Research objectives	Crops				
	Sorghum (%)	Pearl millet (%)	Chickpea (%)	Pigeonpea (%)	Groundnut (%)
Resistance to yield reducers					
Physiological constraints	21	13	10	8	17
Pests[1]	49	38	24	36	58
Actual yield increase *per se*	5	15	18	8	4
Grain quality improvement					
Nutrition quality	9	10	9	8	—
Consumer preference	5	5	3	2	
Others					
Cross location adaptation etc.	11	19	42	38	21
Total	100	100	100	100	100
Actual number of projects	(38)	(40)	(45)	(51)	(42)

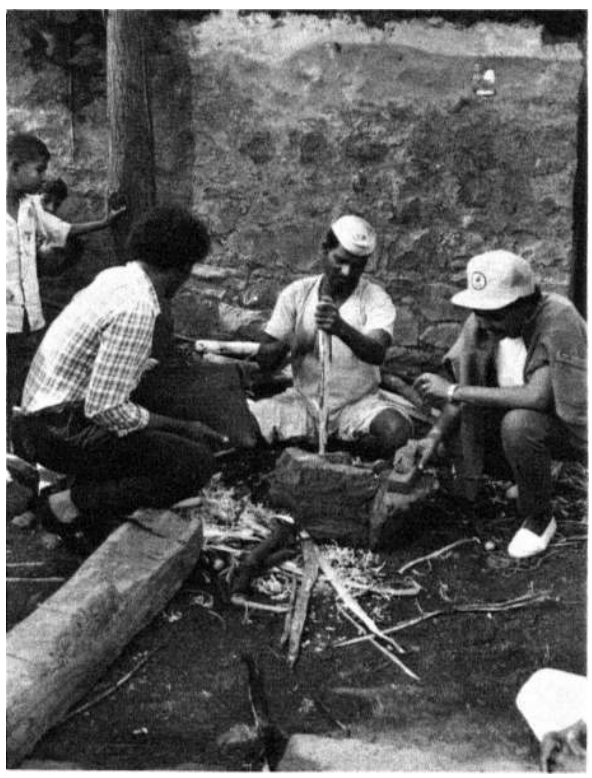
1. Includes research projects on diseases, insects, and *Striga*.

Lanka, and all had at least a bachelor's degree and some field experience in agricultural research.

The main objectives of the training program were to enhance the ability of the participants to identify constraints to agricultural development in the SAT and to evaluate means of alleviating the constraints through technological and institutional change. We also aimed to develop the participants' familiarity with principles and methods used by economists in interdisciplinary agricultural research. The training program also was intended to strengthen linkages between social scientists at ICRISAT Center and those working in national research institutions in the SAT.

We covered the following areas of economic research in depth during the program:

principles and methods of data collection;
on-farm research;
site description for technology design;
yield-gap analysis;
adoption studies;
budgeting methods and their applications;



African trainees watching an Indian craftsman repair a traditional bullock-drawn blade harrow.

- whole-farm modeling and mathematical programming;
- economic assessment of new technologies;
- impact analysis;
- marketing studies; and
- allocation of resources to research.

The lectures were interspersed with case-studies and visits to villages and farms. The response of the participants encourage us to repeat this training program.

Workshops, Conferences, and Seminars

Workshop on Common Property Resources

A Ford Foundation workshop on common property resources research was held at ICRISAT Center, 19-20 January. Common property resources (CPRs), despite their valuable role in farming systems, are one of the most neglected areas both by researchers and planners. 1CRISAT took an initiative in undertaking research on CPRs in 1982. Influenced by this work, the Ford Foundation decided to support research on CPRs in several areas of India. Following a request that ICRISAT should orient others in the methodology approach of CPR research, 15 researchers engaged in Ford Foundation-supported CPR research were invited to the workshop. At the meeting, the methodology and approach to the problems were discussed, and a mechanism was worked out to ensure coordination of research and a periodic exchange of results.

Looking Ahead

Emphasis of our future work is shifting from constraint identification to assessment of options for overcoming constraints. We shall suspend the collection of village data in India in progress for the past 10 years, but we hope to arrange village studies in collaboration with other institutes. We will also increase our efforts to assess technologies in farmers' fields in interdisciplinary collaboration with scientists from ICRISAT and other institutions.

Publications

Institute Publications

El-Swaify, S.A., Walker, T.S., and Virmani, S.M. 1984. Dryland management alternatives and research needs for Alfisols in the semi-arid tropics: an interpretative summary of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 38 pp.

Jha, D., and Sarin, R. 1984. Fertilizer use in semi-arid tropical India. Research Bulletin no. 9. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 76 pp.

Ryan, J.G., Bidinger, P.D., Prahlad Rao, N., and Pushpamma, P. 1984. The determinants of individual diets and nutritional status in six villages of southern India. Research Bulletin no. 7. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 140 pp.

Journal Articles

Kannaiyan, J., Nene, Y.L., Reddy, M.V., Ryan, J.G., and Raju, T.N. 1984. Prevalence of pigeonpea diseases and associated crop losses in Asia, Africa and the Americas. Tropical Pest Management 30(1);62-71,

Matlon, P.J., and Spencer, D.S. 1984. Increasing food production in sub-saharan Africa: environmental problems and inadequate technological solutions. American Journal of Agricultural Economics 66(5):671-676.

Mueller, R.A.E. 1984. Agricultural markets in the semi-arid tropics - note on workshop held at the International Crops Research Institute for the Semi-Arid Tropics, Hyderabad. Quarterly Journal of International Agriculture 23(2):177-181.

Conference Papers

Jodha, N. S. 1984. ICRISAT research and human nutrition. Pages 91-112 *in* International agricultural research and human nutrition (Anderson, P.P., Berg, A., and Forman, M., eds.). Washington, D.C., USA: International Food Policy Research Institute.

Matlon, P.J. 1984. Technology evaluation: five case studies from West Africa. Pages 95-118 *in* Coming full circle: farmers' participation in the development of technology (Matlon, P., Cantrell, R., King, D., and Benoit-Cattin, M, eds.). Ottawa, Canada: International Development Research Centre.

McIntire, J. 1984. Survey costs and rural economics research. Pages 71-82 *in* Coming full circle: farmers' participation in the development of technology (Matlon, P., Cantrell, R., King, D., and Benoit-Cattin, M., eds.). Ottawa, Canada: International Development Research Centre.

Ryan, J.G.,and von Oppen, M. 1984. Global production and demand for sorghum and millet to the year 2000. Pages 41-61 *in* Agrometeorology of sorghum and millet in the semi-arid tropics: proceedings of the International Symposium, 15-20 Nov 1982, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Srivastava, K.L., Virmani, S.M., and Walker, T.S. 1984. Farming systems research in a watershed framework: experience related to Vertisol management in semi-arid tropical India. Pages 352-371 *in* Animals in the farming system: Farming Systems Research Symposium, 31 Oct-Nov 2 1983, Kansas, USA. Manhattan, Kansas, USA: Kansas State University.

Vierich, H. 1984. Accomodation or participation? Communication problems. Pages 17-26 *in* Coming full circle: farmers' participation in the development of technology (Matlon, P., Cantrell, R., King, D., and Benoit-Cattin, M., eds.). Ottawa, Canada: International Development Research Centre.

Theses

Engelhardt, T. 1984. Economics of traditional small-holder irrigation systems in semi-arid tropics of south India. Ph.D. thesis, University of Hohenheim, Hohenheim, West Germany.

Miscellaneous

Matlon, P.J., Cantrell, R., King, D., and Benoit-Cattin, M. (eds.) 1984. Coming full circle: farmers' participation in the development of technology. Ottawa, Canada: International Development Research Centre.

TRAINING