ICRISAT
Research Highlights
1981

International Crops Research Institute for the Semi-Arid Tropics

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit scientific educational institute receiving support from a variety of donors through the Consultative Group on International Agricultural Research. Donors to ICRISAT include governments and agencies of Australia, Belgium, Canada, Federal Republic of Germany, France, India, Japan, Mexico, the Netherlands, New Zealand, Nigeria, Norway, Sweden, Switzerland, United Kingdom, United States, and the following international and private organizations: Asian Development Bank, European Economic Community, Ford Foundation, International Bank for Reconstruction and Development, International Development Research Centre, International Fertilizer Development Center, International Fund for Agricultural Development, the Leverhulme Trust, and the United Nations Development Programme. All responsibility for the information in this publication rests with ICRISAT, where trade names are used this does not constitute endorsement of or discrimination against any product by the Institute.

Cover, on-farm testing of ICRISAT's farming systems technology at Taddanpally, A.P., India: clockwise -farmer sows using equipment developed at ICRISAT; ICRISAT scientist and farmers discuss cropping strategies in a field of intercropped sorghum and pigeonpea; winnowing the harvested pigeonpea. (See reports on pages 34 ff and 40 ff.)

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was founded in 1972 and was the first center created by the Consultative Group on International Agricultural Research (CGIAR). ICRISAT is one of 13 centers in an international research network. Its headquarters and main research farm, ICRISAT Center, is near the village of Patancheru, 25 km northwest of Hyderabad, India. Other ICRISAT scientists are posted in six African countries and in Mexico and Syria.

ICRISAT's mission is to improve the yield, stability, and food quality of its five mandated crops—sorghum, pearl millet, pigeonpea, chickpea, and groundnut, and to improve the quality of life among the more than 700 million of the world's poorest people who live in the semi-arid tropics (SAT).

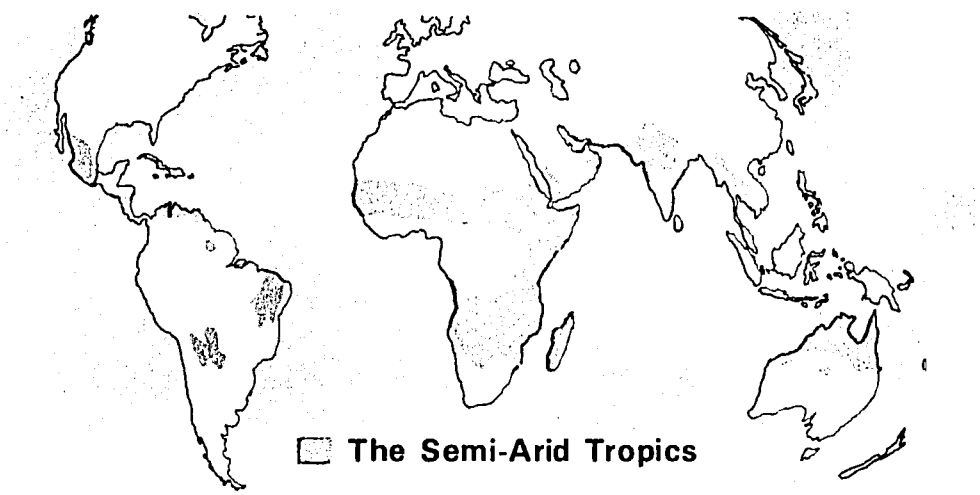
The SAT environment is harsh, its soils are nutrient-poor, and effective rainfall is limited to only 2.0-4.5 months a year. The total area of the SAT, nearly 20 million square kilometers, covers all or part of 49 countries on five continents. It includes much of India, two wide zones in Africa, areas in Southeast Asia and South America, and parts of Mexico and Central America.

All five crops of concern to ICRISAT are of major significance in the SAT, which produce 55% of the world's sorghum, 95% of the pearl millet, 90% of the chickpea, 96% of the pigeonpea, and 67% of the groundnut. Except for groundnut, these crops are basically subsistence food crops mainly for on-farm consumption.

Because these traditionally-grown crops are low-yielding compared with yields in temperate climates and with their potential yield in the SAT, they are being extensively researched by ICRISAT.

To achieve the objectives of ICRISAT's mandate, its staff functions via multidisciplinary research programs and through linkages with national scientists and other international agricultural organizations. ICRISAT's research programs include sorghum, millets, chickpea, pigeonpea, and groundnut in crop improvement, and farming systems and economics in resource management. A training program teaches new technologies to young scientists from SAT countries.

Through this integrated activity ICRISAT seeks to improve yields, production, nutrition, and the quality of life of millions of small farmers in the SAT.



Introduction

Research Highlights is an annual ICRISAT publication which presents a concise overview of the main achievements of research workers at ICRISAT Center and at its overseas stations in several countries in Africa, and in Syria and Mexico. Their efforts and the cooperative inputs of national scientists, workers in extension, and other agencies in India and other countries in the semi-arid tropics have helped ICRISAT take another big stride forward in 1981 towards fulfilling the objectives of its mandate. Our excellent working relationships with many universities and research organizations in non-SAT countries have also contributed to our progress.

Living standards are not going to be miraculously upgraded by the advent of one or two new discoveries for SAT farmers. Instead, the spectrum of improved agriculture and life styles is made up of many vital inputs—improved seeds, essential fertilizers, effective soil management, better utilization of rainfall, appropriate cropping systems, supplementary irrigation, motivation for adoption of technologies, and the elimination of socioeconomic constraints.

All these inputs and the needs for gathering new information and knowledge about them provide essence for ICRISAT's existence and for its activities for the poor farmers of the SAT.

Our global sorghum improvement research is ICRISAT's largest program. During 1981, outstanding yield gains with improved varieties were reported from trials in India, several African countries, and Thailand. The potential for increasing sorghum production from its low average of 800 kg/ha in SAT countries is evidenced by yields exceeding 3800 kg/ha in some of ICRISAT's growing range of newly generated varietal materials.

Pearl millet is the most important cereal crop for the drier, semi-arid South Sahelian Zone of Africa. Material from Africa has been used to breed plants resistant to mildew and ergot, two major millet diseases. This year a hybrid developed from Senegalese and Nigerian germplasm has yielded 14-29% more than a standard hybrid.

Good progress has been made in developing chickpea lines resistant to major diseases. Special emphasis is being placed on breeding for resistance to the pod borer, *Heliothis*, which is the most damaging pest of chickpea. In

southern India, some early-maturing selections have shown outstanding resistance to this insect.

Several promising early-maturing pigeonpea lines have been identified. This work has been in response to the demand for short-duration varieties that can be fitted into a double cropping system with wheat or maize. Late-maturing pigeonpea lines from our program have reached the advanced yield testing stage in India.

Substantial progress has been made with groundnut. Some advanced lines, selected for postrainy season conditions, showed very high yield potential, nearly 7 tonnes/ha, and significantly outyielded the national checks at ICRISAT Center. They are now being tested in the national trials system. ICRISAT scientists have successfully utilized some wild species of groundnut. Hybridization of this material with the cultivated groundnut has produced progeny with high levels of resistance to foliar diseases, particularly rust.

Our Farming Systems Program in cooperation with Indian research organizations has intensified work on technology to double-crop deep Vertisols (black soils) in India. In the postrainy season, 20 million ha of Vertisols are single-cropped. This is an area larger, for example, than Syria. India's food production would be substantially increased if these soils could be made to grow two crops annually.

Technological options for profitable cropping on previously fallowed Vertisols have been examined by the Economics Program; intercropping maize with pigeonpea can increase profits by 600%. The Program has also developed a method to assess the performance of cultivars in multilocation and multiyear trials.

Our genetic resources activities increased in 1981; accessions for all ICRISAT mandate crops totalled 6498, bringing the grand total to 71,402. Great emphasis is being placed on salvaging primitive landraces from many regions of the world. They, and wild species too, possess new and desirable genetic traits which SAT plant breeders can use to broaden the gene pool and improve productivity

ICRISAT also acts as a resource center for germplasm. In 1981, the Institute supplied over 17,000 samples to scientists in 45 countries, mainly in the SAT, for use in their crop improvement programs.

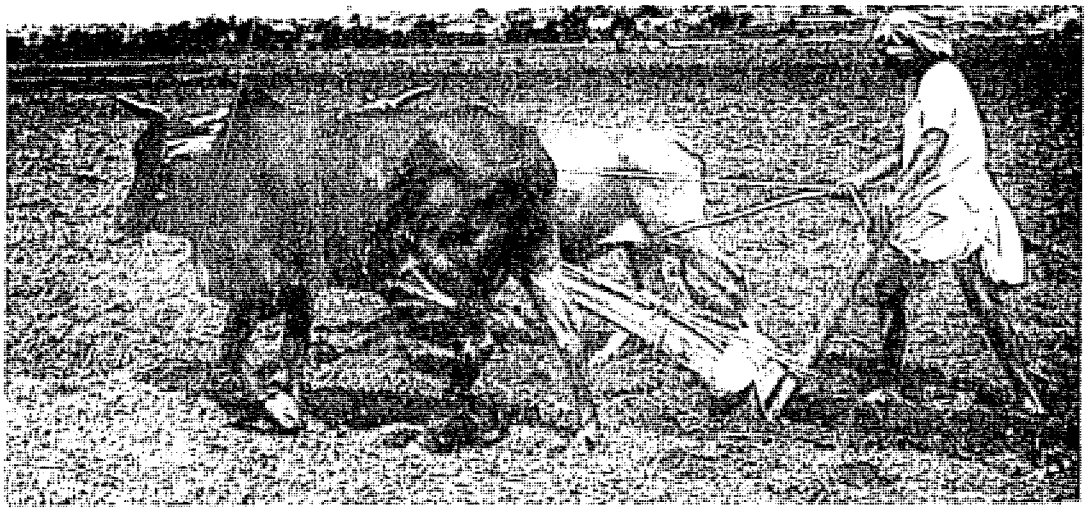
The Institute's Program of International Cooperation was active in the Indian subcontinent, West Africa, southern Africa, Southeast Asia, West Asia, and Mexico. In late 1981, work commenced on the site of ICRISAT's Sahelian Center near Niamey, in Niger.

At ICRISAT Center, 113 persons completed training in 1981, which brings the number to more than 530 since the inception of our Training Program.

Nine workshops, conferences, and specialist meetings were hosted by ICRISAT. Nearly 9000 visitors came to ICRISAT Center, of which about 2500 were farmers.

This review highlights the achievements and progress we made in 1981. These gains reflect the efforts, dedication, and expertise of our scientific workers. They heighten our sense of purpose to serve and optimism for the farmers and their families in the SAT.

L.D. Swindale
Director General



Cereals

Sorghum and millet, which are the major cereals of concern to ICRISAT, are grown extensively in the semi-arid tropics as staple foodstuffs because they are able to withstand dry conditions. In terms of world food production, sorghum and millet are the fourth and fifth most important cereals; together, they are second to rice in cultivated area in the developing countries. Generally they are the subsistence cereals of the poorest countries and the poorest people in those countries.

In calorie intake they rank first in Africa, and third in Asia and the Middle East. Recent reports predict substantial deficits in cereals in the developing world by 1990. The International Food Policy Research Institute (IFPRI) estimates that India will then have a 20 million tonne shortage of cereals, if present trends of production, population growth, and demand for food continue. The African SAT countries, where food production is declining, will have per capita deficits nearly 10 times as great as India. The demand for sorghum and millet in developing countries has increased by more than 2.5% per annum, but their annual growth in supply has been only 1.8% and 1.2%, respectively.

These assessments make it imperative to increase present production urgently. ICRISAT scientists are aware of this urgency and are focusing intensive research on the pro-

A sorghum scientist admiring heads of SPV-351, a promising variety developed at ICRISAT.

duction of cultivars with improved and stable yield; with resistance or tolerance to drought, insect pests, diseases, and parasitic weeds; and with responsiveness to whatever improved levels of management the SAT farmer can provide.

Sorghum

Considerable emphasis has been given to the development of simple, inexpensive selection criteria for screening large numbers of germplasm and breeding material for sources of resistance to the main factors reducing sorghum yields in the SAT. Progress has been achieved in identifying some good stable sources which are being incorporated into improved varieties and hybrids with encouraging results.

Our Varieties in National and Cooperative Trials

In India our improved varieties, SPV-351, SPV-386, and SPV-393 were evaluated in national trials and farmers fields and have again given good and significant grain yield performance over several locations. SPV-351 has been evaluated in the Indian national trials for the last 3 successive years with outstanding performance, and has now been entered into the 1982 prerelease All India Minikit and State-Wise Special Minikit Trials.

Our improved varieties gave good yields in three farmers' fields in Andhra Pradesh, India, ranging from 2400 to 3300 kg/ha at the high-fertility level, and 1460 to 1900 kg/ha at the low-fertility level, versus 1400 and 1000 kg/ha at high- and low-fertility levels respectively for the local variety over all locations. SPV-351 was the top yielder at all locations, with mean grain yields of 3300 and 1900 kg/ha at high- and low-fertility levels respectively.

In Africa several improved varieties were evaluated in national and international trials in Nigeria, Senegal, Upper Volta, Mali, Sudan, Ethiopia, Somalia, Kenya, Tanzania, Malawi, Zambia, Zimbabwe, and Botswana. Some of these varieties have been selected for further testing in their national trials or as valuable breeding lines in their programs.

Such new high-yielding varietal material has the potential to make substantial contributions to sorghum production in the SAT.

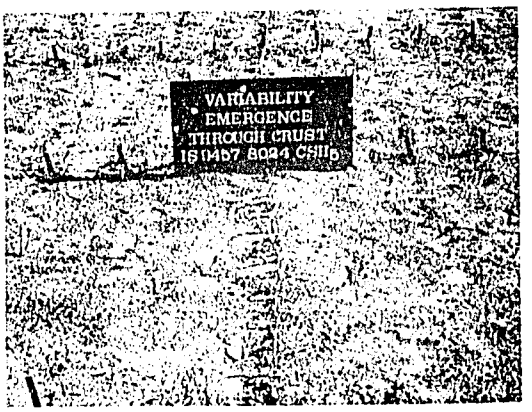
Soil Crusting Studies

Crop establishment is a serious problem in soils in semi-arid regions where uncertainty of rainfall is a limiting factor on crop production. Soil crusting is a major limitation on seedling emergence from these soils.

Collaborative research is being conducted at ICRISAT Center, and at Haryana Agricultural University, Hissar, to screen varieties for their ability to emerge both through soils with high surface temperature and crusts.

The techniques that have been developed have been used to identify seven varieties

Varietal difference is evident in the ability of seedlings to germinate through a soil crust in a screening nursery.



which possess superior abilities to penetrate crusted soil. Preliminary results indicate that there are distinct varietal differences.

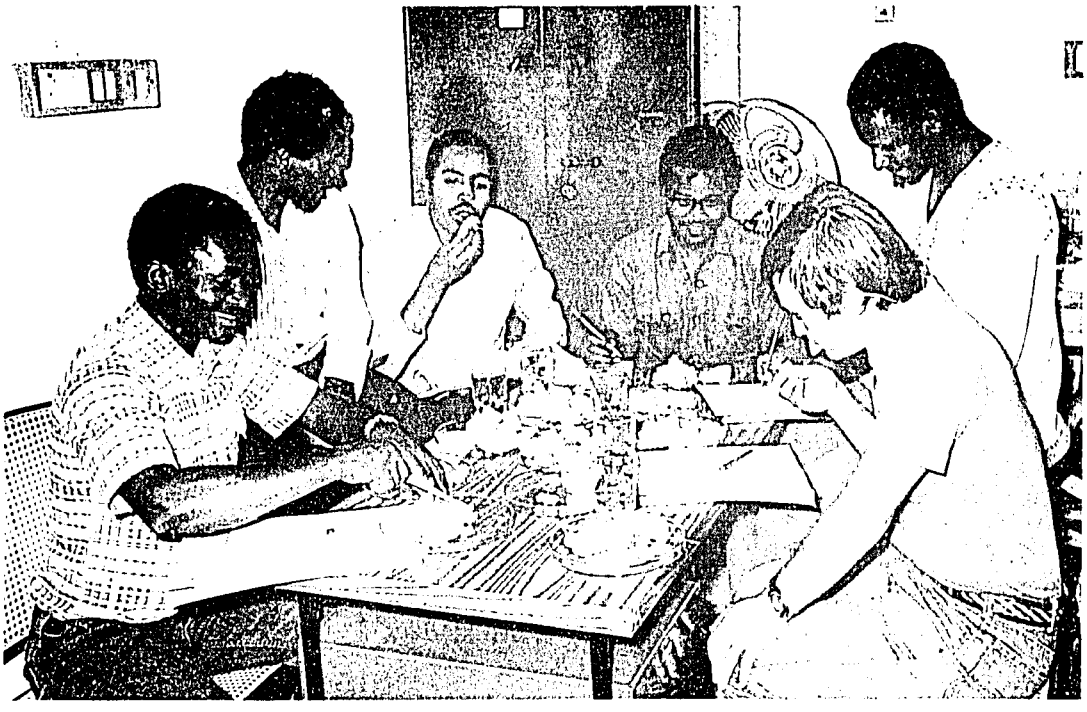
Midge Research

In much of the world sorghum midge (*Contarinia sorghicola*) is a destructive pest of grain sorghum. At ICRISAT Center research is being conducted on midge biology, and on screening and breeding for resistance.

Scientific screening for resistance has been difficult because of the day-to-day variation in midge populations and the differences in flowering of sorghum genotypes. To overcome these difficulties ICRISAT scientists have adapted several techniques to evaluate resistance to midge. Five varieties were found to be promising.

To evaluate resistance against midge, a sorghum head is covered with a bag containing midge insects.

ICRISAT trainees participating in the taste evaluation of ugali, *a common sorghum food in East Africa.*



Two Valuable International Symposia

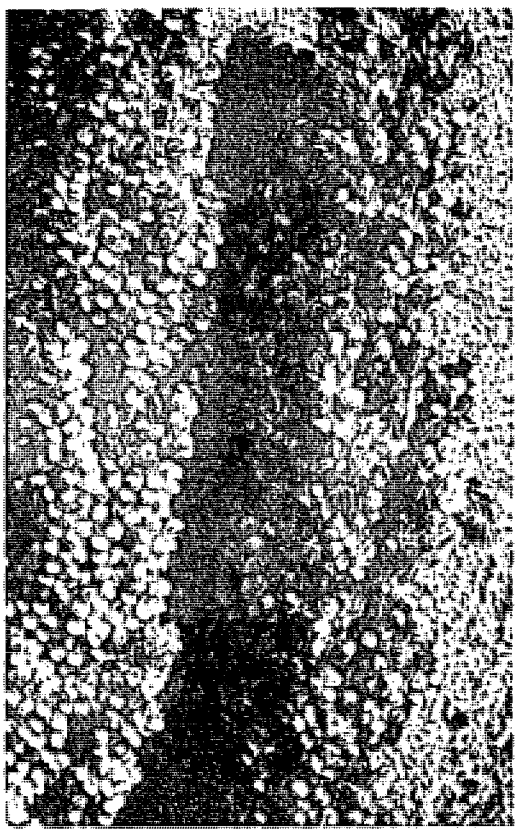
ICRISAT hosted two international symposia at ICRISAT Center in late 1981, i.e., Sorghum Grain Quality, and Sorghum in the Eighties. They were sponsored by the USAID Title XII Collaborative Research Support on Sorghum and Pearl Millet (INTSORMIL), the Indian Council of Agricultural Research (ICAR), and ICRISAT.

The Grain Quality Symposium was unique in that it was attended by food technologists, home economists, nutritionists, breeders, biochemists, food processors, engineers, pathologists, entomologists, physiologists, and economists. This diverse group of scientists discussed existing knowledge on preparing sorghum as a food, its grain structure, milling, laboratory methods for evaluating and improving food quality, nutrition, consumer acceptance, marketing, and food standards.

The Sorghum in the Eighties symposium was attended by 245 scientists from 37 countries involved in sorghum research, production, and utilization. Significant research results during the last decade were reviewed, and research and development priorities for sorghum in the next decade were identified.

The proceedings of both symposia will be published by ICRISAT in 1982.

Resistance to grain mold is evident in the white-seeded sorghum variety (left), while the other variety is susceptible (right)



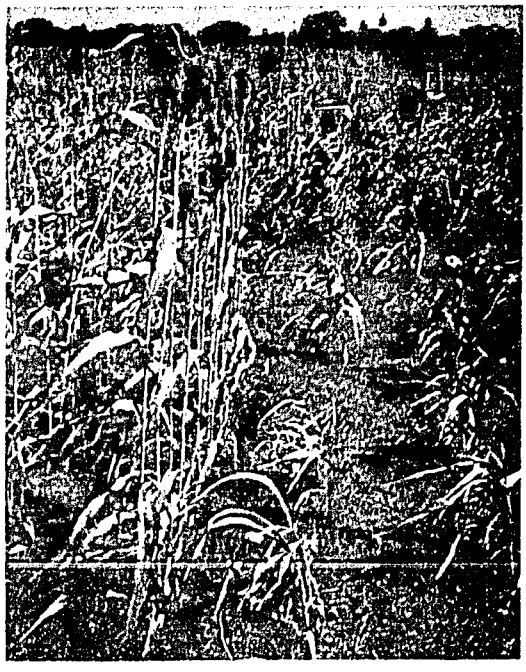
Other Highlights

- Screening for resistance to the grain molding fungi, *Fusarium moniliforme*, *F. semitectum* and *Curvularia lunata*, was effectively conducted using sprinkler irrigation without artificial inoculation.

- Improved field techniques have been developed to screen for resistance to the parasitic weed, *Striga*. Using these techniques, 21 improved breeding lines in good agronomic background have been identified with useful levels of resistance to *Striga*.

- As part of the program to diversify and improve seed parents of hybrids, 380 male-sterile seed parents are being developed and 50, which are now at an advanced stage, are under evaluation in hybrid combination.

Sorghum plants attacked by Striga, a *plant that parasitizes roots of sorghum.*



In a field trial with sorghum and Striga asiatica, *sorghum lines possessing resistance (left) and susceptible lines (right) are distinguishable.*

A sorghum scientist inspecting a plot of a hybrid involving a parent from the population breeding program.

Pearl Millet

Of the several millets, pearl millet (*Pennisetum americanum*) is the staple cereal best suited to the climate of the hot, drought-prone regions of Africa and the Indian subcontinent. Millets are especially important because they are the main source of calories for millions of people in the driest areas of the SAT.

Pearl millet was domesticated in semi-arid West Africa, a region that still contains the richest sources of genetic diversity. ICRISAT obtained from Africa the pearl millet germplasm that contained the genes needed for stable resistance to downy mildew and ergot, which are major diseases of the crop.

Disease Control

Downy Mildew

The development of downy mildew resistance within an ultra downy mildew susceptible pearl millet has been demonstrated. The study was commenced in 1979 by using 2000 plants of an ultra susceptible cultivar, IP 7042, from Chad. By self pollination and sibbing—intermating selected individuals of the same cultivar—it was possible in 1981 to select six downy mildew-free progenies and a further 12 others with less than 10% downy mildew.

These results demonstrate that resistance to this disease can be located and utilized even in highly susceptible cultivars. These findings offer exciting possibilities and great scope for the improvement of resistance in any pearl millet cultivar (except a totally inbred line), while at the same time maintaining the original adaptive features of the cultivar. Good cultivars which become susceptible to downy mildew may not therefore have to be discarded.

In other experiments on downy mildew, it was established that two different mating types of the causal fungus are required for sexual reproduction of resting spores. The phenomenon is called heterothalism and this is the first time that this phenomenon has been detected in graminaceous downy mildews. The finding has important implications for pathogen variability. Further studies are needed to determine whether additional mating types exist and to what extent in natural populations.

Ergot

In the program to develop sources of resistance to this disease, more than 2000 lines ranging from the second to the eighth generation (F_2-F_8) were selected in 1981. They were derived from crosses involving lines of African and Indian origin of low susceptibility to ergot. During the rainy season 13 lines, which were then being tested at the F_8 stage, were found highly resistant to ergot. They also were highly resistant to smut and downy mildew in India.

In other experiments, ergot control through pollen management was evaluated. A hybrid was sown with and without a pearl millet pollen donor line. Test plots that included the pollen donor had significantly less ergot than plots without a pollen donor. The trial results add further evidence to the potential of ergot control via pollen management.

Smut

Millet Program scientists have developed an effective technique to screen for smut resistance in the field at ICRISAT Center where natural smut incidence is low. Just prior to head emergence on millet plants, a suspension of spores is injected into the boot-leaf, which contains the inflorescence. Inoculated plants are bagged and the plots are irrigated three times each day with sprinklers to maintain optimum conditions for disease attack.

This technique will allow a high number of millet lines to be screened with no possibility of escape.

Identifying Drought Resistance

Trials have been conducted using a moisture gradient technique to screen millet in the field for drought resistance. Previously, the method of withholding irrigation water to impose a moisture stress in off-season crops was used.

In the moisture gradient technique, a single row of closely spaced overhead sprinklers is used to apply a linear gradient of water at right angles to the sprinkler line. The varieties being evaluated are planted in strips at right angles to this line, along the moisture gradient. With this technique, gradients of stress are created and varieties are compared for their responses across a range of stress environments.

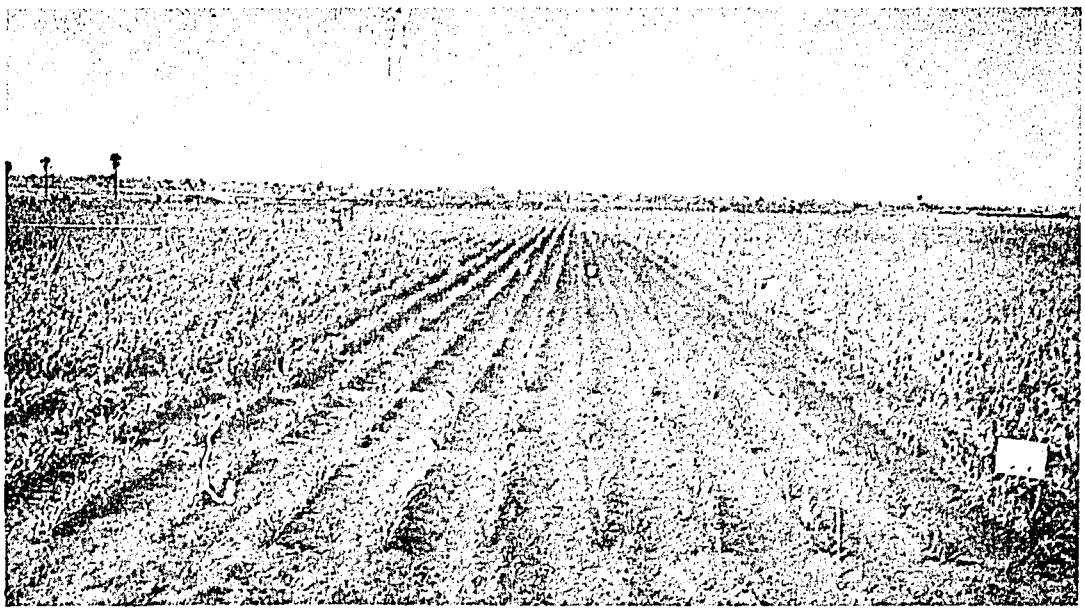
Using statistical analysis methods, it is possible to evaluate the yielding ability of breeding lines or cultivars at any selected level of moisture stress, particularly in severe stress environments. A further application of the line source technique is to evaluate the stability of advanced breeding lines that already possess established yield potential, disease resistance, etc., under stress.

Both analyses are important in breeding programs developing cultivars for rainfed environments. The new stress technique also includes procedures for separating the stress escape and nonstress components of yield performance.

Nitrogen Fixation

It has been known for some time that some cereals and grasses are able to fix atmospheric nitrogen. Because poor nitrogen

Midseason drought stress is imposed on pearl millet by using the line source technique at ICRISAT Center during the hot summer season. The single row of overhead sprinklers applies a moisture gradient at right angles to the sprinkler line.



availability in some soils is a limiting factor to production, and since fertilizers are seldom available to poor farmers, nitrogen fixation is already playing an important role in cereal production in the SAT, and could be further improved through research. ICRISAT has demonstrated differences in nitrogen fixing ability in cultivated lines of pearl millet and shown that much higher levels of activity exist in the wild relatives of pearl millet. A cross between elephant grass (*Pennisetum purpureum*) and pearl millet showed activity equal to the elephant grass.

The Millet Program has continued to study the potential for exploiting nitrogen fixation by various bacteria associated with millet roots, and pot and test tube screening techniques have been developed to more closely examine the various components of this association.

Soil samples, taken from around the roots of millet plants from areas in the traditional millet production districts of Gujarat and Maharashtra in northwest India, were examined for nitrogen-fixing bacteria. It was found that populations of these bacteria can be as high as 50 million per gram of soil in the root region of millet.

Detailed bacterial studies on 3760 isolates of bacteria from these soil samples showed that 42% possessed nitrogenase activity. These were classified into 24 colony types. A total of 59 apparently different types of bacteria will be further studied in detail for characterization and identification.

The overall goal of the nitrogen fixation studies on pearl millet is to develop techniques to select for nitrogen-fixing capacity and to incorporate it into advanced breeding material.

Breeding

In the Source Material project, a recent acquisition from Togo has proved to be an impressive parent for yield, earliness, grain size, and appearance in variety crosses in widely different environments in African countries and places in India.

Hybrid ICH 220, the male parent of which was developed from Senegalese and Nigerian sources, gave 29% higher yield than the standard hybrid BJ104 in the All India Coordinated Millet Improvement Project, AICMIP, and an average of 14% more than the local checks in the International Pearl Millet Adaptation Trial, IPMAT.

A new dwarf seed parent ICM ms 81A, which is resistant to downy mildew in India, was made available to Indian scientists in April 1981 in time for kharif evaluation.

The effect of recurrent selection, a breeding method that enables the simultaneous concentrating of favorable genes for many trials in populations, was assessed over three cycles in one of our breeding populations, the Medium Composite. Grain yield increase averaged 4.7% per cycle without adversely affecting height and maturity. Resistance to downy mildew was increased.

One of the downy mildew free selections from the initially ultra susceptible cultivar 7042 developed through several generations of selection under severe downy mildew pressure at ICRISAT Center.

Pulses

The pulse crops chickpea and pigeonpea occupy very important positions in semi-arid farming systems both for human nutrition and for restoring soil fertility.

Because more than 85% of pigeonpea and 80% of chickpea are produced in the Indian subcontinent, this region is receiving the highest priority for improving the two crops. The dietary requirement of all pulses in India is 17 million tonnes, but present production is 12 million--a 30% deficit. The rapid decline in the availability of pulses and the widening gap between supply and demand is causing great concern among poor people of the Indian subcontinent and other pulse-consuming areas of the world.

Chickpea and pigeonpea are traditionally low-yielding crops. But ICRISAT is optimistic about increasing their production based on encouraging results in the improvement program, and about the possibilities for widening their adaptation (that is, adjustment to new or altered environmental conditions).

Chickpea

Chickpea plays a vital role as a grain legume in dryland subsistence agriculture in India, Pakistan, Bangladesh, Nepal, Afghanistan, East Africa, West Asia, the Middle East, southern Europe, North Africa, Mexico, and South America.

This pulse is a short-statured annual plant with a relatively high harvest index; the grain weighs 40-60% of the above-ground plant parts at harvest. Chickpea is adapted to growing in postrainy seasons either on stored moisture or with irrigation. It has a high protein content (22-24%) and when consumed with such cereals as rice, sorghum, millet or wheat it provides an adequately balanced protein-calorie diet.

Two main types of chickpea are marketed. Kabuli (garbanzo) is the smooth, white-colored, large-grain chickpea that is commonly spring-sown to produce a summer crop in the Middle East, the Mediterranean region and in the Americas. Desi (garbanzo porquero) chickpea has smaller, rougher seeds that range from yellow to black in color. It is autumn-sown to raise a winter crop in Asia, especially in the Indian subcontinent and in Ethiopia.

Chickpea yields in the SAT are low (about 700 kg/ha) due to the use of locally developed primitive varieties, poor production practices, and relegation of the crop to areas with impoverished soils.

ICRISAT's main efforts are directed to developing improved cultivars and genetic stocks of kabuli and desi chickpeas capable of higher and more stable yields in traditional and nontraditional situations.

Major activities are concentrated at ICRISAT Center at Patancheru to produce short-duration desi genotypes suited to peninsular India; at Hissar in northern India to produce long-duration desi and kabuli types adapted to areas of northern India; and at ICARDA, our sister institute at Aleppo in Syria, to produce kabuli types adapted to both winter and spring sowing in western Asia and North Africa.

Chickpea Diseases

Good progress has been made in identifying lines resistant to the major diseases. In our field, greenhouse, and laboratory tests we have identified 50 lines resistant to *Fusarium* wilt, 48 to dry root rot (*Rhizoctonia batatic-*

Ascochyta blight is a major disease of chickpea. In this disease nursery that at Tarnab, Pakistan, ICRISAT lines with resistance to Ascochyta *blight are very evident.*

ola), 18 to black root rot (*Fusarium solani*), 4 to *Botrytis* grey mold, and 22 kabuli and 60 desi lines resistant to *Ascochyta* blight. Screening for *Botrytis* was carried out at the G.B. Pant University of Agriculture and Technology at Pantnagar, India, and for *Ascochyta* through cooperative work with ICARDA. For the first time, *Fusarium* wilt resistance was detected in kabuli types.

The major pathogens that attack chickpea are *Fusarium* wilt, root rots, *Ascochyta* blight, and stunt. We are using several crossing methods to incorporate resistance to these diseases into adapted genotypes. In view of the significant loss of production that any of these diseases can cause, we are giving great emphasis to transferring disease resistance, including multiple resistance, into adapted cultivars. For instance we have made crosses to combine resistance to *Fusarium* wilt and root rot with resistance to *Ascochyta* blight and stunt.

The first finding of bean yellow mosaic virus (BYMV) on chickpea under natural field conditions in India was reported.

Disease Survival

Because disease-causing organisms occur in soil, a knowledge of their presence and viable longevity in soil is an important factor affecting crop rotation practices.

ICRISAT scientists found that *Fusarium* wilt fungus can survive in soil for 39 months and for up to 24 months in infected chickpea roots buried 60 cm deep. Results obtained so far with dry root rot fungus show that it can survive for up to 36 months in the soil. *Ascochyta* blight fungus investigations have shown that deep sowing of chickpea seed reduced seed transmission of the disease.

Seed Treatments

Seed-borne disease can be controlled by using appropriate seed dressings. We have determined that seed dressed with Benlate T (30% benomyl + 30% thiram) can remain free of chickpea wilt fungus even when planted 1 year later. This treatment should eliminate the chances of moving the fungus from ICRISAT to cooperators within India since they all plant the seed within a year after treatment.

In northern India, Botrytis *grey mold of chickpea causes heavy losses on chickpea crops. ICRISAT scientists have identified lines showing resistance to the disease.*

We also confirmed that a seed dressing with Calixin M (30% Tridemorph + 30% maneb) eradicates *Ascochyta* blight fungus on the seed.

Good Performance Lines

In our cooperative trials in the All India Coordinated Pulse Improvement Project (AICPIP), ICCC-4, a medium-duration desi type, continued to perform well in the central zone of India and is being evaluated in larger-scale trials in Rajasthan and Gujarat in 1981/82. Crosses are in progress to introduce resistance to *Fusarium* wilt into this cultivar.

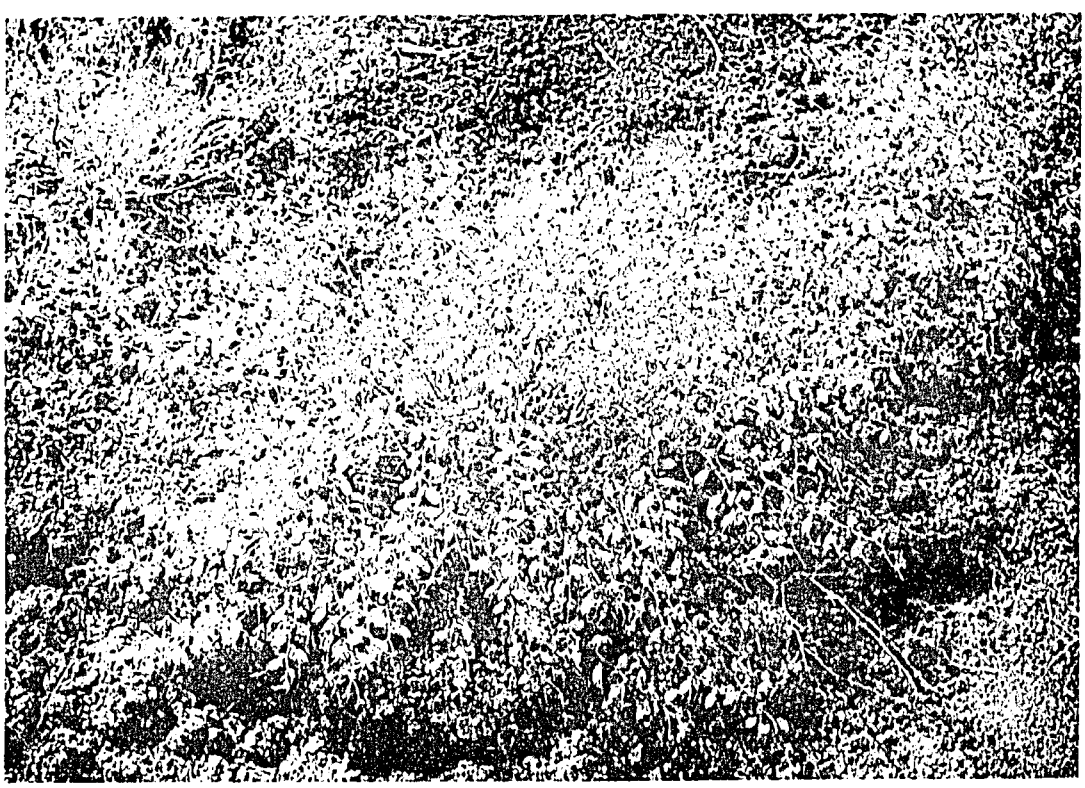
The lines ICC-22, -23, and the germplasm line P-326 have been promoted from the Gram Initial Evaluation Trial (GIET) to Gram Coordinated Variety Trials (GCVT). ICCC-13 has been retained in the GCVT for a 4th year and last year it was one of the top entries in the GCVT in peninsular and central India.

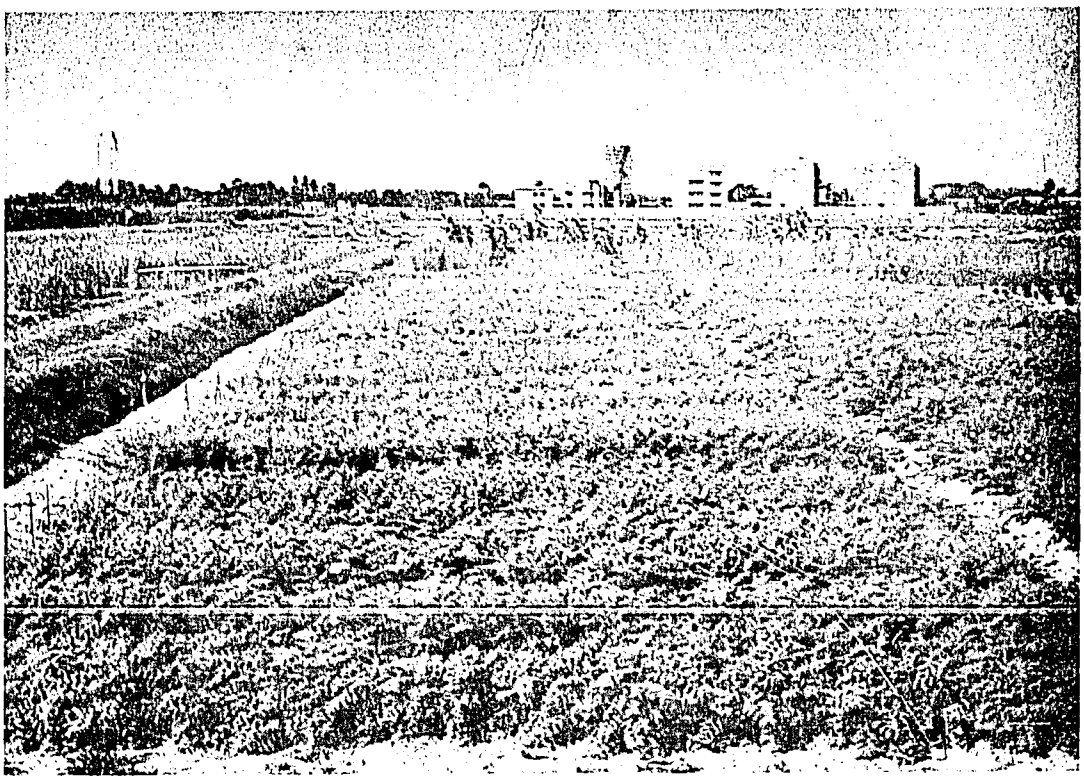
The kabuli types ICCC-25 and -26 have been retained in the Coordinated Kabuli Trial for a 2nd year and three new entries have been added.

International Cooperation

We supplied 132 sets of trials and nurseries to 57 cooperators in 24 countries. Nineteen high-yielding, wilt-resistant desi lines have been included in International Screening Nurseries and 20 in the International Wilt and Root Rot Nursery. A wider range of kabuli lines with wilt resistance is now available.

ICRISAT has an extensive crossing program to evolve improved chickpeas. Crosses with wild species have produced well-podded progeny.





Chickpea breeders at ICRISAT cooperate with breeders in 24 countries. These fine looking chickpeas are growing in an international nursery trial at Ishurdi, Bangladesh.

Segregating populations from crosses made between *Ascochyta* resistant desi types and northern Indian materials have been supplied to Pakistan and north India.

Working with our sister institute ICARDA, we screened nearly 4000 desi germplasm accessions at Tel Hadya, in Syria. We also supplied seed of 101 advanced kabuli lines for inclusion in ICARDA nurseries.

Heliothis Studies

The *Heliothis* pod borer is usually the most damaging pest on chickpea in most areas. Work on developing resistant lines has continued and we have supplied seed of our selections that show most *Heliothis* resistance to several cooperators in the All India Coordinated Pigeonpea Improvement Program. The best of our early-maturing selections were outstanding at Coimbatore in southern India. There our line ICC-506 had the lowest percentage of pod damage and gave the highest yield.

This line and other selections that have been found to be resistant to *Heliothis* attacks are now being utilized in our breeding program. We are currently screening F_4 progenies of crosses between resistant material and high-yielding cultivars.

The Max-Planck Institute, Munich, is cooperating with ICRISAT on investigating resistance mechanisms to *Heliothis*. Our more resistant chickpea selections tend to exude greater concentrations of malic acid from the glandular hairs which cover the plants from the seedling stage onwards.

Other Highlights

- Screening against soil-borne diseases in the multiple-disease sick plot at ICRISAT showed 95 lines to possess multiple resistance to wilt and root rots. Forty of these lines have been included in the 1981/82 International Chickpea Root Rots/Wilt Nursery.

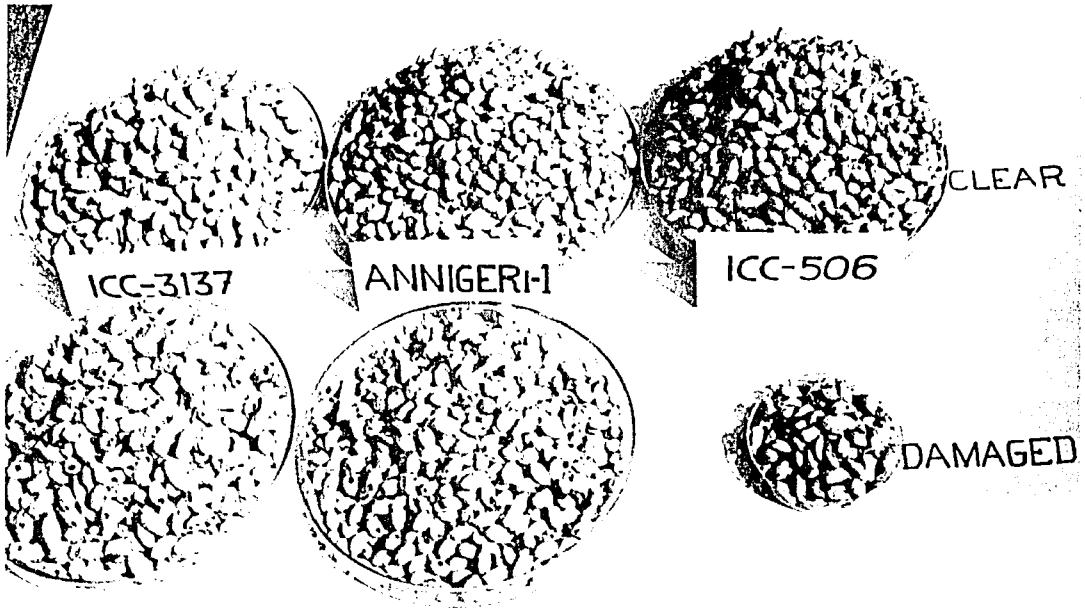
- Chickpea plots grown at ICRISAT Center under conditions nonlimiting for nutrients and water gave grain yields of 2800-3200 kg/ha and high productivities of 26-30 kg/ha grain per day, thereby indicating that substantial increased yields can result from irrigation in peninsular India.

- Irrigation and fertilizer application increased the protein content of seed.

- Genotypes with two pods at each node have a yield advantage of up to 11% over normal single-podded cultivars. ICRISAT researchers have identified 25 lines with the double-podded character.

The most damaging pest of chickpea is the pod borer, Heliothis. *Most of the pods on this plant exhibit typical damage caused by this insect.*

Chickpea ICC-506 shows fewer pods damaged by Heliothis *than the check Annigeri and susceptible ICC-3137*



Pigeonpea

Pigeonpea is grown on about 2.5 million ha in India, and there are substantial areas of cultivation in eastern and southern Africa, Southeast Asia, and the Caribbean. Although this plant is a perennial shrub with woody stems and branches, it is normally grown as an annual crop. It is deep-rooted and drought-tolerant, which makes it a useful crop in erratic and low rainfall areas. Because its average yields are low (700 kg/ha), pigeonpea production has been pushed into marginally productive lands in the SAT by higher yielding cash crops.

Although it is primarily a seed crop, the large amount of vegetative material produced can provide valuable fodder and fuel. The seeds have a high protein content (about 20%), and are a staple food in parts of the SAT. They are usually consumed with rice, sorghum or other cereals, a combination which gives an excellent balance of amino acids in the diet.

The overall objective of the pigeonpea improvement program at ICRISAT is the development of genotypes with high stable yields of acceptable grain quality under a range of cropping situations.

Several pigeonpea types are needed—short-duration types responsive to high inputs and suited to sole-cropping systems so as to fit into a rotation with wheat; types suitable for the postrainy season in southern and central India; medium-duration types for southern India and West Africa; long-duration types for intercropping in central and northern India and eastern and southern Africa; and large-seeded vegetable types, particularly for the Caribbean.

Photosensitivity Studies

A major handicap in improving yield in pigeonpea has been the absence of daylength-insensitive plants responsive to inputs such as fertilizers, irrigation, and pesticides. Traditional pigeonpea cultivars are short-day plants, i.e., they will flower only in daylengths of less than 12 hours.

At the University of Queensland, Australia, we have supported genetic studies that have indicated that daylength response is probably controlled by three genes. This finding will enable the development of daylength insensitive lines for more stable production in short-duration production systems.

Good progress is being made at our cooperative research station at Hissar in northern India in developing short-duration, high-yielding, disease-resistant pigeonpeas. Several promising large-seeded lines, which mature in about 105 days, have been identified. When used in rotation with wheat, these lines provide more time for farmers to prepare their fields for wheat.

Late-Maturing Pigeonpea

Our excellent cooperation with the All India Coordinated Pulse Improvement Project has continued. Whereas in previous years we have had promising early- and medium-maturing pigeonpea lines in the All India Coordinated Trials (AICT), in 1981 we entered two promising late-maturing lines for the first time in the AICT-3. The lines are ICPL-310 and ICPL-311, which were bred at our cooperative station at Gwalior where we are concentrating on developing improved late-maturing genotypes adapted to traditional production systems.

Disease Resistance

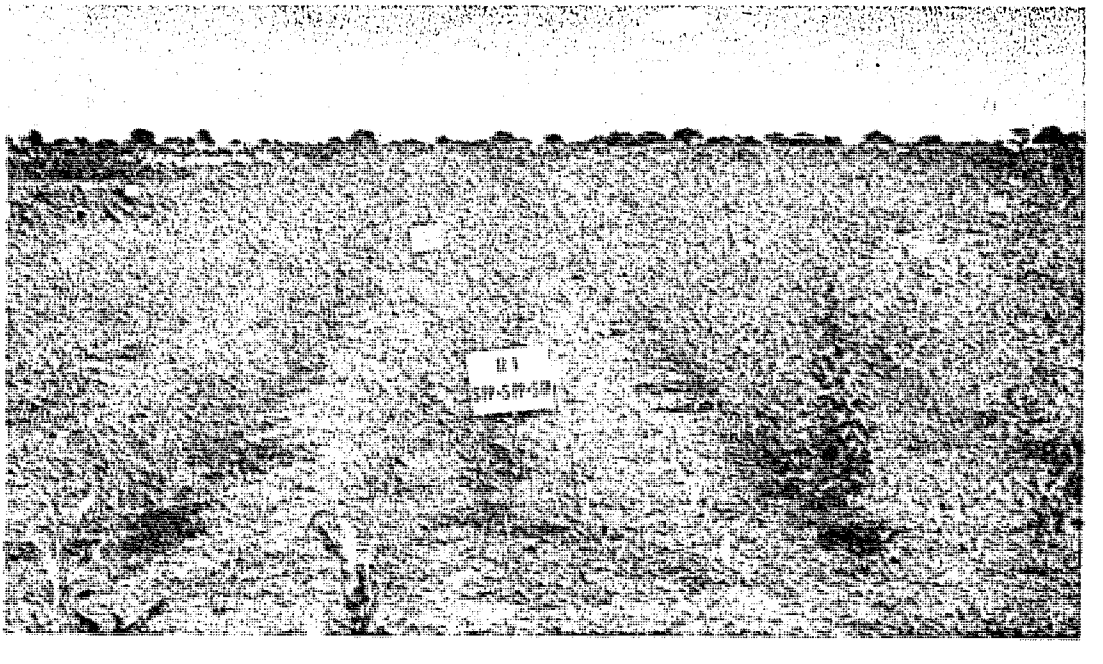
Our scientists have developed high-yielding pigeonpea lines with resistance to *Fusarium* wilt, sterility mosaic, and *Phytophthora* blight.

Sterility mosiac, one of the major diseases of pigeonpea, produces bushy plants with reduced growth, and yellow and green mottled leaves. On infected plants, there are

Heliothis armigera *larva, the major pest of pigeonpea, feeding on a pod.*

few or no flowers, thus rendering the plants sterile. Although scientists have not identified the causative agent of sterility mosaic, it is believed to be a virus; the agent is transmitted by the mite *Aceria cajani.* These mites are carried by wind and can spread the disease at least 450 meters downwind, but less than 25 meters against the prevailing wind.

When sorghum is intercropped with pigeonpea there is a reduction in Fusarium *wilt in the pigeonpea crop.*



This year ICRISAT modified its sterility mosaic disease screening procedure from a spreader-row technique—planting test material between regularly spaced well established infected rows—to an infector hedge technique. This consists of the advanced planting of only four rows of a susceptible cultivar in the upwind end of the field. These rows are inoculated with infected mites and, by the time normal planting occurs, a well infected hedge has developed. An excellent disease spread was obtained; indicator rows showed 99.4 to 100% infection. The technique, which is much simpler than using spreader rows, enabled the effective screening of 2 ha of breeding material.

Rabi Yield Increases

In India the postrainy-winter season of October through January is known as the *rabi* season. The days are short, dry, and cool. ICRISAT is developing and evaluating pigeonpea crop systems in the *rabi* in an attempt to increase production, utilize fallow land, take advantage of residual moisture, and capitalize on pigeonpea's short-day photo response.

The medium-maturing cultivar C-11 and the late-maturing cultivar NP(WR)-15 were used in a trial on a Vertisol (black soil) to evaluate optimum sowing date and number of irrigations for high yield. The results showed that irrigation gave a greater yield increase from a September sowing than from October or November sowings. These irrigations in the September planting gave the maximum yield increase over no irrigation, i.e., 160% for C-11 and 95% for NP(WR)-15.

Other Highlights

- Epidemiology studies at ICRISAT Center showed that a 1-year fallow between pigeonpea crops reduced *Fusarium* wilt incidence from 85% under continuous cropping,

A major disease of pigeonpea is sterility mosaic. To screen for resistance, ICRISAT grows four rows of a susceptible cultivar to form an infector hedge. This technique ensures uniform and efficient screening.

[illegible]

to about 20%. The incidence of wilt on pigeonpea when intercropped with sorghum for the 2nd year was 24%.

- Wilt (*Fusarium udum*) was found to be the most serious disease of pigeonpea in a survey conducted in Kenya, Malawi, and Tanzania.

- A 15-state, 5-year survey of pigeonpea pests in India showed damage by lepidopteran pests predominated in southern India; damage by podfly was more prevalent in central and northern India.

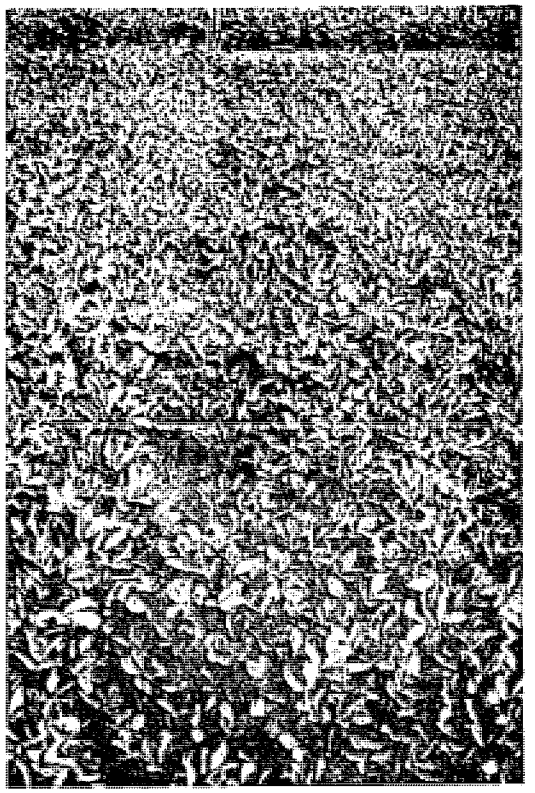
- High-quality rhizobial inoculants have been successfully produced at ICRISAT using a fermenter, carriers, and packaging from Australia. ICRISAT has now built a fermenter from low cost local material, and has produced rhizobia, which are being tested on local carriers and packaging material.

Samples of pods collected from farmers' pigeonpeas are sorted according to their pest damage characteristics for ICRISAT's surveys in India.

Groundnut

The cultivated groundnut, *Arachis hypogaea*, is a native of South America and is now grown throughout the tropical and warm temperate regions of the world. It is the most important legume crop of the semi-arid tropics (SAT), with production equalling the combined total for dry beans and chickpeas, which are the next two grain legumes of importance. Because groundnut contains 25% protein and 50% oil, it is an important food crop in the SAT. Also, it is the only mandate crop of ICRISAT that enters into world trade to any extent because it is one of the world's major sources of edible oil.

Two-thirds of world groundnut production is grown in the SAT, most of it on small farms. The major constraints to production are pests, diseases, and undependable rainfall patterns. These factors result in yields averaging only about 800 kg/ha compared with 3000 kg/ha or more in developed countries. Yields can be substantially increased by management of these yield-reducing factors.



Because of unreliable rainfall in the semi-arid tropics, plant breeders and physiologists are endeavoring to develop drought-resistant groundnut lines, such as the one (center) illustrated in this drought screening trial.

High-Yielding Cultivars

High-yielding cultivars are being developed for use in the national programs. By growing two generations a year at ICRISAT Center, ICRISAT has produced advanced breeding lines and entered them into national variety trials in the relatively short time span of 5 years. One generation has been advanced in the rainy season and the second generation in the postrainy season under irrigation. However, cultivars did not always perform equally well in both seasons and results indicated that there were strong interactions between genotype and environment. Therefore material for specific seasons has been selected, with particularly good results for the irrigated postrainy season when foliar diseases are relatively unimportant and water is not so often a limiting factor.

At ICRISAT Center some of these advanced lines yielded 6.8 tonnes/ha compared with 3.3-5.0 tonnes/ha for nationally released cultivars. Seventeen of the best lines were entered into the newly constituted

Indian National "Rabi-Summer" Trials. There is an expanding area of summer-grown irrigated groundnuts in India due to the high yields being obtained, which are often double those of the rainy-season crop. At four of the five trial sites, ICRISAT lines gave the highest yield and one line, ICGS-35, was first in yield when the results were analyzed across all the locations.

Other cultivars were entered in the rainy-season national trials. In the initial Evaluation Trial (Virginia Bunch) at ICRISAT Center, ICGS-5 ranked first (1609 kg/ha), and significantly outyielded the national check cultivar, Robut 33-1 (1345 kg/ha). The line ICGS-1 ranked first (2159 kg/ha) in the Initial Evaluation Trial (Spanish Bunch) but did not significantly outyield the national check, J11 (2104 kg/ha). This high-yielding material is being supplied to cooperators in many countries.

Rusts and Leaf Spots

On a world-wide basis, rust and leaf spots are major causes of yield loss in groundnuts. Rust is caused by the *Puccinia arachidis*, while the most important leaf spots are caused by the fungi *Cercospora arachidicola* and *Cercosporidium personatum*. At ICRISAT Center the most damaging diseases are rust and late leaf spot (*C. personatum*); their combined attack causes yield losses of 50-70% in susceptible cultivars when grown in the rainy season without fun-

Groundnut germplasm resistant and susceptible to rust and leaf spot undergoing field testing at ICRISAT Center

Late leaf spot, Cercosporidium personatum, *can cause economically important yield losses in groundnut. Many genotypes with good resistance have been located in screening trials at ICRISAT. The difference between resistant and susceptible genotypes is obvious.*

gicide protection. Although fungicides can be used for control of the diseases, the chemicals and application equipment are expensive.

It is therefore important to find sources of resistance to the pathogens and to combine this resistance with good agronomic characters such as high yield.

Screening of germplasm for rust and leaf spot resistance was commenced at ICRISAT in the 1977 rainy season. The rust resistance previously reported from the Americas for "Tarapoto" and other lines has been confirmed, and additional sources of resistance have been identified. ICRISAT now has 33 genotypes with good resistance to rust, i.e., they rate below 5 on a 9-point disease reaction scale (1 = immune; 9 = over 50% of foliage destroyed by disease). The screening work has been done in collaboration with US Department of Agriculture groundnut scientists in Georgia and Puerto Rico and has resulted in the joint release of rust-resistant breeding lines. International testing has shown that the resistant genotypes have very similar rust reactions when grown in the USA, India, and China.

Prior to 1977 several genotypes were reported to be resistant to *C. arachidicola* or to *C. personatum* leaf spots in the Americas. One genotype was reported resistant to both leaf spots. Screening for resistance to late

leaf spot at ICRISAT has confirmed some of the reported resistances and additional sources have been identified. ICRISAT now has 21 genotypes with good resistance (below 5 on the 9-point scale) to this disease. Because the incidence and severity of early leaf spot disease (*C. arachidicola*) is too low at ICRISAT to permit effective field screening for resistance, materials are being screened at other locations where the disease is more prevalent. The preliminary results are promising.

The prospects of locating sources of multiple disease resistance to rust and late leaf spots are good, and 15 genotypes with excellent levels of resistance to both diseases have been found. Several of these genotypes originate from South America. Some are low-yielding and have rather poor pod and seed characters. However, they can outyield the best available susceptible cultivars when grown in the rainy season without fungicide control.

The rust- and leaf-spot-resistant sources are being used in the breeding program. In 1981 one of the advanced lines, which is rated 3 for rust resistance, yielded 5.0 tonnes/ha compared with 3.9 tonnes/ha for the rust-susceptible check, Robut 33-1, under unsprayed conditions. These breeding lines also have superior agronomic characters and are being supplied to our cooperators in many countries.

Nitrogen Fixation

Groundnuts are inoculated by a group of *Rhizobium* strains classified as the "cowpea miscellany". Most of the cultivated soils of the tropics appear to have relatively large populations of this type of *Rhizobium* and groundnut is usually nodulated in most of these soils. Inoculation with effective *Rhizobium* strains has increased pod yields in fields where groundnuts had not been grown previously. However, there are very few reports on yields being increased by inoculating groundnuts with effective *Rhizobium* strains where the crop has been previously planted.

Over the last 4 years, ICRISAT has conducted *Rhizobium* inoculation trials at ICRISAT Center and at other sites in Gujarat and Karnataka in cooperation with the All India Coordinated Oilseeds Research Project. Groundnuts had also been grown in the very recent past at these sites. In preliminary trials, significant yield responses were obtained with the groundnut cultivar Robut 33-1 and the *Rhizobium* strain NC 92. Further trials at ICRISAT Center have continued to show significant pod yield increases of 18 to 34% with the same strain and cultivar. At the Dharwar station, in Karnataka state, a 40% yield increase was obtained. One of the ICRISAT breeding lines, ICGS-15, also gave a significant yield increase when inoculated with strain NC 92.

Because Robut 33-1 has been released as an improved cultivar in Andhra Pradesh, inoculation tests are being conducted on farmers' fields with strain NC 92 in conjunction with the State Department of Agriculture and the Andhra Pradesh Agricultural University.

We have also found that it is better to apply the inoculum directly to the soil by mixing the peat containing the *Rhizobium* with water and then pouring this mixture into the furrow just ahead of the person planting the seed. Direct application of the *Rhizobium* to the seed, a common inoculation method for legumes, tends to decrease germination of the fragile groundnut seed.

Seven cultivars and germplasm lines have been tested for their ability to fix nitrogen. One line, NC Ac 2821, showed a very high rate of fixation and has been used as a parent in the breeding program. A derivative of this cross was shown to have high yield potential and indicates that there is a possibility of increasing yield by incorporating high nitrogen fixing lines in a breeding program.

Nitrogen fixation studies with groundnut have shown that applying the Rhizobium-*peat inoculum mixture directly to the soil ahead of planting produces better nodulation results than treating the seed.*

Other Highlights

- A rapid screening technique has been developed for postharvest seed dormancy in early-maturing groundnuts. From hybrid populations of crosses made between dormant late types and nondormant early types, five lines have been selected that have early-maturity morphological characteristics and incomplete dormancy for 15-23 days.

- Initial investigations showed that substantial variability exists in groundnuts for adaptation to drought. Some cultivars were able to survive droughts that killed others and some had a superior ability to maintain pod growth under dry conditions.

- Doubling the number of chromosomes of some wild species has made them valuable parents in crosses with *Arachis hypogaea*. The progeny have high levels of resistance to foliar diseases, especially rust. Advanced interspecific hybrids have been supplied to breeders and have shown high yield potential in preliminary tests.

Genetic Resources

One of the important opportunities for crop improvement lies in the variability and availability of the world's genetic resources. There is a considerable amount of diversity worldwide that is not yet assembled and conserved. Scientists have become increasingly aware of the need to salvage landraces (locally evolved primitive cultivars), and to capture new and desirable genetic traits, including those in wild species.

In January 1979, ICRISAT commenced a Genetic Resources activity in order to strengthen and enrich its own crop improvement programs and to make invaluable genetic material available to scientists all over the world. The Genetic Resources

*This is foxtail (*Setaria italica*) ISe-376 from Assam, one of the six minor millets assembled at ICRISAT Center.*

[illegible] Such [illegible]

Unit collects, evaluates, maintains, conserves, documents, and exchanges germplasm of the Institute's five mandate crops and six minor millets for present and future utilization. The germlasm collection missions are always launched in close collaboration with national and/or international organizations.

Germplasm collection work was accelerated in 1981. The new crop germplasm accessions were sorghum 3278, pearl millet 748, pigeonpea 318, chickpea 47, groundnut 1608, and minor millets 499. They came from Burma, Malaysia, Botswana, Ethiopia, Zambia, Gambia, Philippines, Mozambique, Tanzania, Ghana, northern Nigeria, and several areas in India. For all these crops, the total number of accessions is now 71,402. This is probably the largest collection of germplasm of these crops assembled at one place. However, we still consider that this total is rather small compared with what is yet uncollected.

Every year we notice that there is a growing awareness that germplasm of any crop is an indispensable raw material for crop improvement. Collection expeditions are conducted jointly with national scientists in countries in Africa, Asia, and Central America, and often with the support and close collaboration of the International Board for Plant Genetic Resources (IBPGR).

Evaluation in Collection Areas

The Genetic Resources Unit has recently commenced evaluating germplasm

at or near the area of collection. Such evaluation ensures that landraces can be characterized and utilized properly, which may not be the case when they are assessed outside their area of natural adaptation. Accordingly, pilot projects have been initiated in Upper Volta and Niger with pearl millet, and in India with chickpea. In Ethiopia, a joint sorghum germplasm evaluation program has commenced with the collaboration of the Ethiopian Plant Genetic Resources Center.

Cereal Germplasm

A major effort was made during the year to assemble more cereal germplasm. Sorghum collections were organized in the Gambella area of Ethiopia and in northern Nigeria, and many *zera-zera*, *kaura*, *fara-fara*, and *guineense* sorghums were collected. The *zera-zera* sorghums from the Gambella region of Ethiopia and Sudan are highly valued for their elite agronomic characters and grain quality.

A special project has been initiated to provide for an effective and easy flow of tropical sorghum germplasm into various sorghum improvement programs around the world. In this plan, the desirable genes from new germplasm are being incorporated by hybridization into the adapted cultivars, a process called introgression. Also, conversion is being used, i.e., converting daylength-sensitive, tall, tropical sorghums into daylength-neutral, short lines by a backcrossing program. The present project uses *zera-zera* landraces from Sudan and Ethiopia, which, although highly valued for their superior agronomic traits, are of restricted utility because of their photoperiod (daylength) sensitivity and height.

Some of the desirable germplasm now assembled includes sorghum and pearl millet lines with several desirable characters. Sorghum lines with good grain quality and glossy leaves have been identified from the germplasm. Glossy plants tend to be more drought-resistant at the seedling stage and show greater resistance to shoot fly than nonglossy lines.

Screening sorghum germplasm for insect and disease resistance continues in collaboration with other disciplines. The following numbers of promising lines were identified with resistance to grain mold (236), leaf diseases (148), shoot fly (233), stem borer (128), and head bug and midge (250). All these lines are being further tested for confirmation and subsequent utilization by crop improvement scientists.

New pearl millet accessions brought the overall total to 14,340. Three new wild spe-

The cultivated pearl millet (right), its closest wild relative, P. violaceum *(left), and their natural cross "Shibra" (center) grow side by side in Bambey, Senegal.*

A farmer in northern Ghana proudly displaying his selected pearl millet germplasm, which he uses as his seed for the next year's sowing. Such traditional seeds are collected and conserved in the ICRISAT gene bank.

cies of *Pennisetum* obtained are *P. schweinfurthii* collected from Sudan, *P. macrostachyum* from Mysore University, and *P. violaceum* from Senegal, Mali, and Niger. New and useful characters such as sweet-stalk pearl millet lines were identified from Tamil Nadu in India and the Central African Republic. Several landraces, such as IP-6271 from Mali, IP-5870 from Senegal, and IP-5383 from Niger, were identified for their high-yielding potential, and are being extensively utilized by millet workers in India and Africa. Several dwarf and male-sterile lines were also identified.

Pulses Germplasm

Introgression work in pigeonpea has made a significant advancement as a result of crossing two Australian wild relatives of pigeonpea, *Atylosia grandifolia* and *Atylosia*

A Tanzanian farmer participating in the collection of germplasm from a perennial pigeonpea landrace.

lanceolata, with cultivated pigeonpea. This is the first time this hybridization has been achieved. It presents new opportunities for utilizing new genetic traits from wild species that have been previously unavailable.

Several pigeonpea landraces, such as ICP-6982 and ICP-2223, have been identified for their high-yielding potential and are currently utilized by breeders. Other investigations have located 49 lines with a potential for photoperiod insensitivity, thereby taking the total number of photoperiod insensitive lines to 787.

Systematic screening by pathologists and entomologists has revealed 48 pigeonpea lines resistant to wilt, 17 to blight, 2 to sterility mosaic, and 83 with some tolerance to pod borer or pod fly, or both.

New morphological types of chickpea have been identified in evaluation and characterization studies. Work on mutations—varying the hereditary material of a cell—has generated new and unique variability in chickpea.

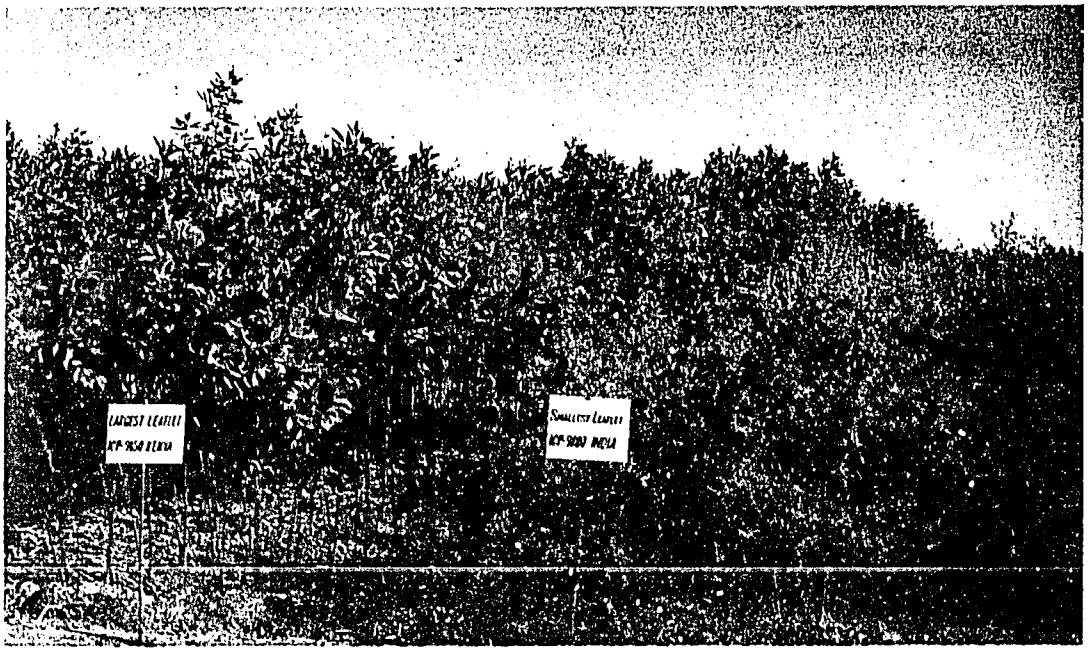
Groundnut Germplasm

A total of 1608 accessions were added which raised the total groundnut accessions to 9911. Five more wild species have been secured. In collaboration with other disciplines, lines resistant to various diseases were identified and they are currently being utilized by the Groundnut Program.

Other Highlights

- Promising groundnut lines with resistance to fungal diseases, peanut mottle virus, and insects were identified.

- A list of descriptors (described charac-



A demonstration of the wide diversity available in pigeonpea: the two ICRISAT accessions with the largest (ICP 9150) and smallest (ICP 9880) leaflets, from Kenya and India respectively.

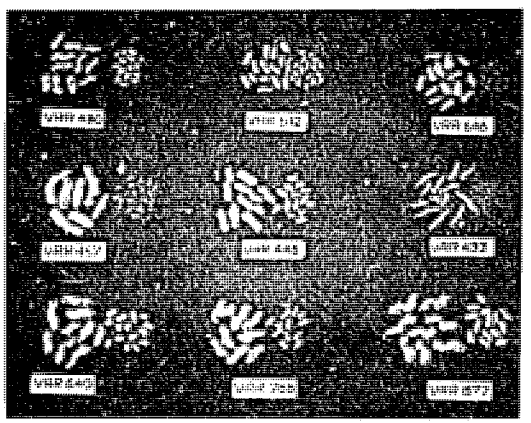
teristics) for pearl millet, pigeonpea, and groundnut has been completed and published in collaboration with IBPGR.

- More than 17,000 germplasm samples were supplied to scientists in 45 countries, mostly in the SAT, for utilization in their crop improvement programs.

- New areas for germplasm collection were identified in western, eastern, and southern Africa for cereals and pulses; in Central and South America for groundnuts and pulses; and in southern and eastern Asia for cereals, pigeonpea, and groundnut.

- The new Genetic Resources laboratory and cold storage facilities at ICRISAT Center are under construction and the transfer of germplasm from temporary storage is planned to take place in 1982.

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



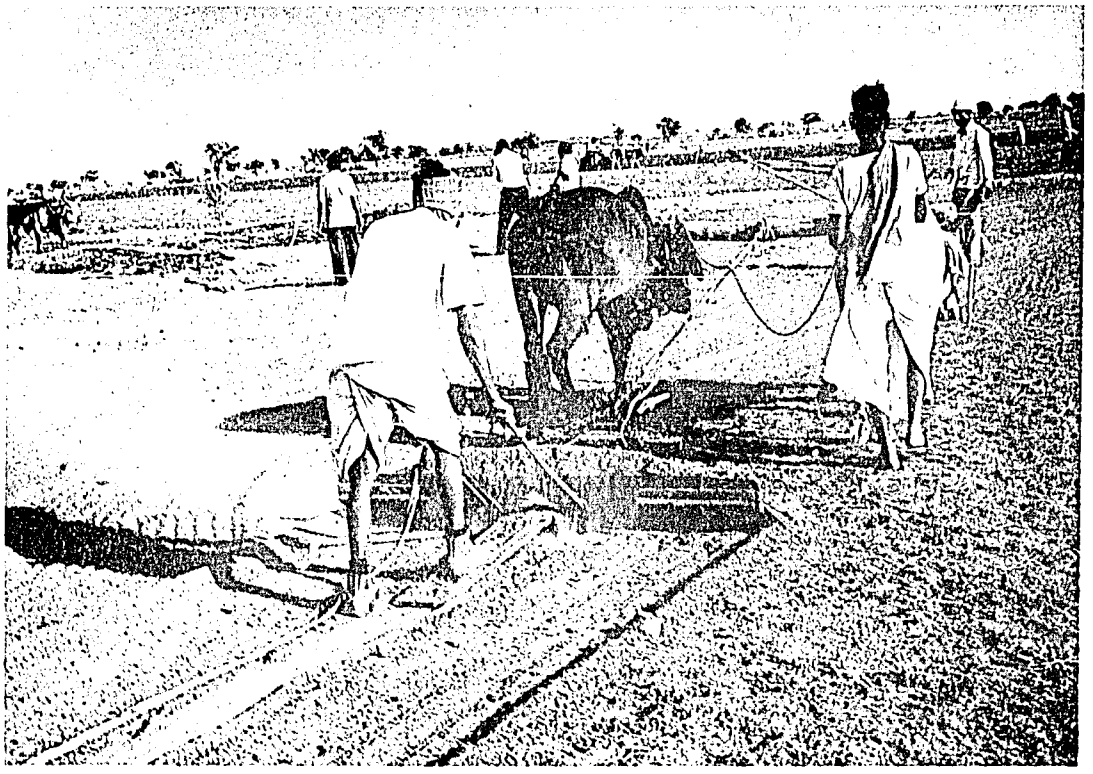
Farming Systems

The main objective of ICRISAT's farming systems research is to develop concepts and techniques for increasing crop production through better use of natural and human resources in the SAT. These research activities involve and integrate studies on a range of diverse soil types, agroclimatic factors, cropping systems, farm power and equipment, and water and soil management techniques. Collaborative investigations are being conducted with national and state research organizations.

Increasing Food Production

In India, cooperative work has commenced with Indian research organizations to test ICRISAT's farming systems technology for the double cropping of deep black soils (Vertisols). At present, about 20 million ha of Vertisols are single-cropped in the postrainy season in SAT India. Due to problems of proper management these soils are traditionally left fallow during the rainy season. If millions of hectares of these soils can be

A farmer carrying out land smoothing prior to preparing broadbeds and furrows.



Sorghum intercropped with pigeonpea at Taddanpally village, Andhra Pradesh, India.

used to grow two crops a year, the practice can add substantially to India's food production.

ICRISAT has developed improved cropping systems to utilize the rainy-season period on these Vertisols. The systems offer a good base to make a quantum jump in the production of coarse grains, pulses, and oilseed crops. In assured rainfall areas, rainy-season cereal crops have been grown without reducing the yields of postrainy-season crops. Maize and sorghum have been shown to be good rainy-season crops. Such cereals intercropped with a long-duration pigeonpea have been particularly promising and have given more stable returns than a sole-crop system.

ICRISAT has started to test and demonstrate its technology for double-cropping deep Vertisols on farmers' fields near ICRISAT Center in cooperation with the Indian Council of Agricultural Research (ICAR), the Andhra Pradesh Department of Agriculture, and Andhra Pradesh Agricultural University.

ICRISAT scientists selected a 15-ha watershed in Taddanpally village in the Medak District of Andhra Pradesh, India. Fourteen farmers are cooperating in the project. The village population is about 400 persons of whom only 20% are literate. The average size of the ownership landholding is 2.8 ha. About 80% of the deep Vertisols are traditionally left fallow during the rainy season. Yields of postrainy-season crops are low. Farmers are poor.

Results from the 1st year are highly encouraging. Rainy-season crop yields were:- maize 1.7 tonnes/ha, mung beans 0.5 tonnes/ha and sorghum 2 tonnes/ha, while the traditional postrainy-season sorghum crop averages only 0.6 tonnes/ha.

It is imperative that the new technology of double cropping on these soils be transferred to Indian agencies for testing and

demonstrating to small farmers. To assist in meeting this need, ICRISAT has trained 56 research and developmental staff from the Indian Ministry of Agriculture and the states of Andhra Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu, and Maharashtra. They will prepare plans for on-farm operational testing of black soil technology and ICRISAT will monitor their progress.

Climatic Characteristics

Agroclimatic surveys are an integral and essential component of evaluating the requirements for farming systems research. Data obtained from such surveys permit a better delineation of the SAT regions to be made and improve the capability for predicting the most appropriate cropping systems for a given environment.

Climatological data of some SAT locations have been analyzed and concepts for utilization of different agroclimatic regions have been developed. Agroclimatologists in the Farming Systems Program have completed studies on the description of the climatic environment of pigeonpea-growing areas in India and compared these with the agroclimatic characteristics of West African regions to indicate the areas most suitable for extending pigeonpea cultivation. In the major pigeonpea-growing areas in India, it was determined that the mean temperatures vary from 26 to 30°C in the rainy season, and 17 to 22°C in the postrainy season. Mean annual rainfall ranges between 600 and 1400 mm, of which 80-90% is received during the rainy season. The growing season extends from 120 to 180 days.

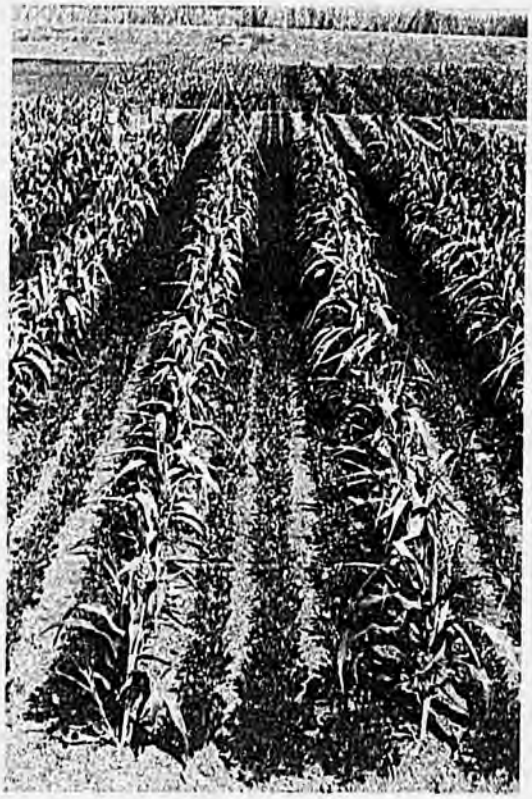
We have proposed revisions of earlier world climatology maps published by Troll which depict the semi-arid tropics. New SAT maps for India, Brazil, and African countries, using an enlarged data base, have been drafted. The revised SAT map of India was developed from data from about 300 locations. Eighty-eight percent of the geographical area of India comes under the tropics. Dry semi-arid tropics—regions with 2 to 4.5 humid months in a year—cover about 57% of India in the proposed revision.

The boundaries for Brazil are based on data from 180 locations. The proposed map of Africa uses data from 300 locations in West Africa and 180 locations in the remainder of Africa.

Intercropping and Moisture Stress

In our cropping systems research we have made a special study of the advantages of intercropping compared with sole cropping, especially under the low moisture and low fertility conditions typical of the SAT. In the summer of 1980 a "line-source" experiment was initiated to examine a very wide range of moisture stress conditions on sole crops and intercrops of millet, sorghum, and groundnut. Sole crop yields ranged from 2500 to 5000 kg/ha under no stress to as little as 100 to 900 kg/ha under severe stress. Intercrop yields decreased less rapidly than sole crop yields as stress increased, and under severe stress sorghum or groundnut intercrop yield exceeded sole crop yield despite the smaller area occupied. For all intercropping combinations the total yield of both crops was higher than sole cropping, and these advantages were relatively greater under moisture stress (44-150%) than under no stress (-2 to 34%). Similar trends were obtained in the summer of 1981, though the maximum advantages under stress were rather lower (up to 58%) because unexpected cloudy weather and rainfall reduced the degree of stress achieved.

These results emphasize the potential importance of intercropping for improving and stabilising yields in the SAT: it may give useful advantages in the wet years and it is even more beneficial in the dry years when yield increases are more urgently needed.



A 'line-source' experiment on moisture stress. In foreground of photo on left, sole sorghum yielding few heads under stress. In foreground of right-hand photo, sorghum intercropped with groundnut, similarly under stress, giving good yields.

Land Management Studies

ICRISAT land and water management engineers have found that the continuously maintained broadbed-and-furrow system in Vertisols has resulted in less compaction and an improved workability. The air-filled porosity and aeration were better than in soil under flat cultivation. Also, a preirrigation shallow cultivation in the cracked furrows of the broadbed-and-furrow system in Vertisols improved water distribution efficiency. It was possible to make a considerable saving in irrigation water and yet maintain chickpea yields.

Fertilizer Nitrogen Efficiency

The response of our mandate cereals to fertilizer nitrogen (N) in the rainfed SAT is uncertain because of the large number of factors involved. The amount and distribution of seasonal rainfall is particularly important. We need to know how the crop responds to major agronomic and environmental factors.

We are using fertilizer N labeled with ^{15}N, the stable nonradioactive isotope of nitrogen, to follow the fate of fertilizer N. In experiments with ^{15}N our soil scientists have found that between 50 and 70% of applied N was

[illegible] ICRISAT [illegible]

recovered in the above-ground parts of the crop. When fertilizer was broadcast on the soil surface or incorporated after broadcasting, recoveries were usually much less than when compared with deep placement of the fertilizer.

Other Highlights

- Cropping systems scientists have confirmed from intercropping studies that a sorghum intercrop could decrease *Fusarium* wilt of pigeonpea and that a millet crop could decrease *Cercospora* and rust diseases of groundnut.

- We conducted a special in-house review of Farming Systems Research at the Institute to evaluate the concepts related to its needs, organization, objectives, and strategies. The review involved ICRISAT Center scientists, West African Program staff, the Director General, and members of the Governing Board. The working papers, major conclusions, and recommendations of the review are being published.

- A diagnostic test was developed for iron deficiency in groundnuts, by a simple extraction of fresh tissue of the unopened bud or first fully-opened leaf using acidified ophenanthroline.

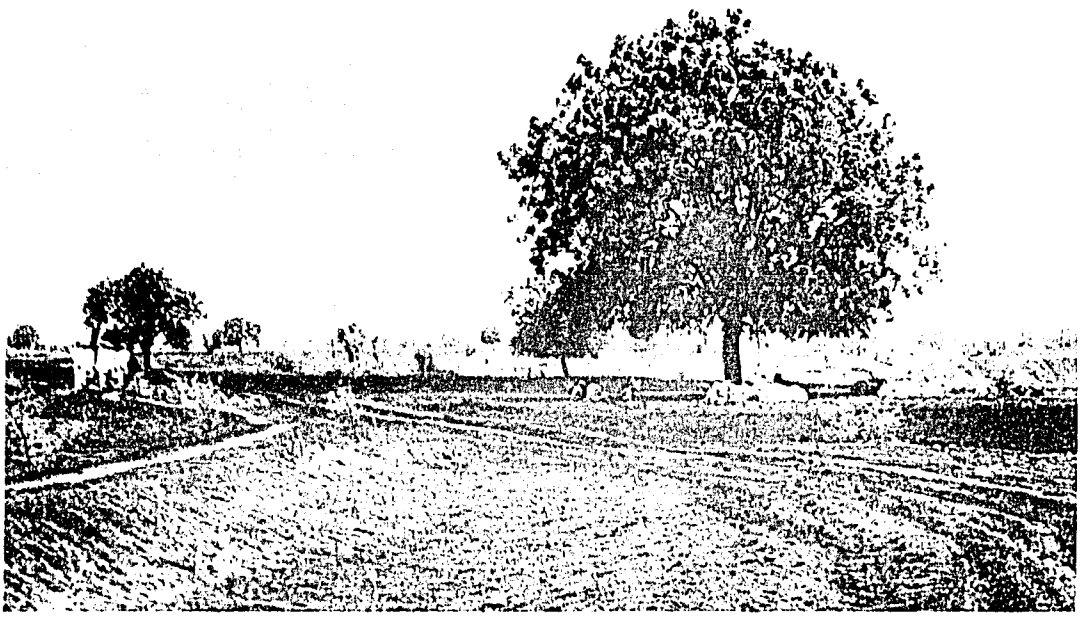
Economics

Economics research is focused on identifying socioeconomic and other constraints to agricultural development in the semi-arid tropics, evaluating options, and making recommendations to overcome these constraints.

The Economics Program conducts multidisciplinary Village-Level Studies (VLS) to understand constraints to food production and development, and to assess prospective technologies. The extent and importance of agricultural risk and risk attitudes are determined and measured. Issues concerning efficiency and equity in research resource allocation are studied. Supply and demand elasticities in markets and consumer preferences for SAT food grains, particularly sorghum, are analyzed.

A major function is to provide data that will help evaluate and ensure that the agricultural technology being developed at ICRISAT is relevant to actual constraints facing SAT farmers, and that the potential for payoff is high. Experiments conducted on-station and on-farm are subjected to economic analysis and the social, organizational, and institutional requirements for successful adoption of new technologies by farmers are then evaluated in on-farm research. This research is conducted in cooperation with scientists in the Farming Systems Research Program of ICRISAT and those in national programs.

Millions of hectares of black soils (Vertisols) are left as fallow in the rainy season. ICRISAT is developing improved technologies to utilize this land during the rainy season.



Rainy-season Fallowing on Vertisols

An analysis was completed of climatic, agronomic, and economic determinants of the extent of rainy-season fallowing in the Vertisols (black soils) of India. The greatest extent of such fallowing occurs in the states of Madhya Pradesh, Maharashtra, and Andhra Pradesh. In these three states, more than 12 million ha remain as fallow during the rainy season and most of this area consists of deep Vertisols.

In a district-level analysis we found that irrigation of bottom lands, soil moisture holding capacities, and annual rainfall were the main factors determining the incidence of fallowing. In dependable-rainfall fallow Vertisol regions, the predicted probability of rainy-season fallowing was inversely related to soil gravel content and slope of the land. The relationship was direct for Vertisols with up to 40% clay content; thereafter it was inverse.

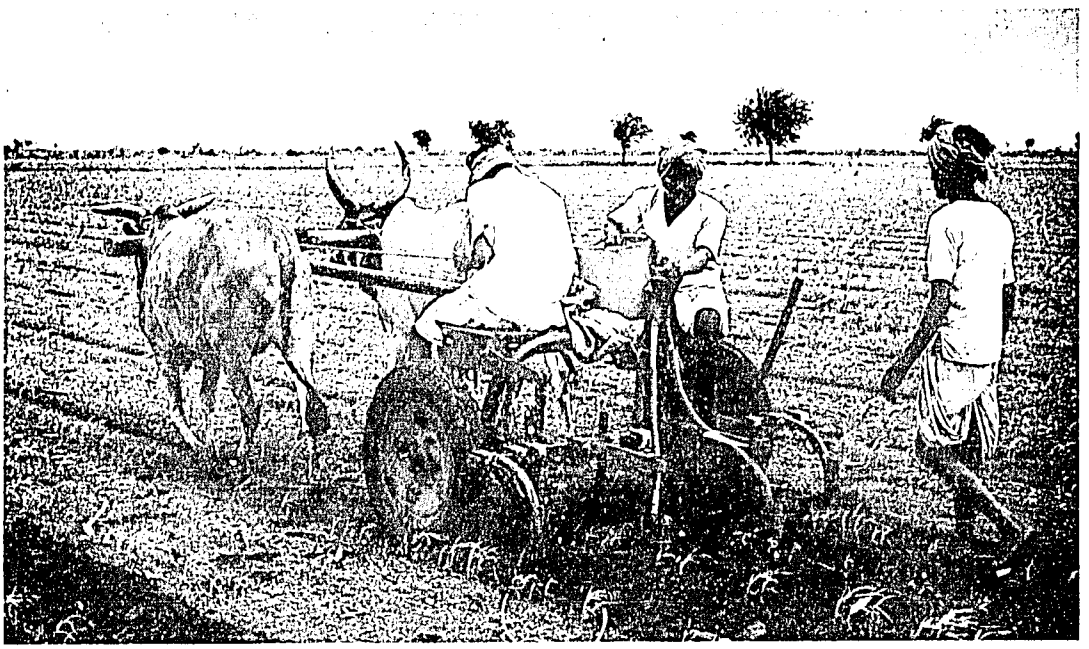
Other analysis showed that rainy-season cropping of Vertisols is likely to be an attractive economic proposition in the relatively assured rainfall areas of Madhya Pradesh.

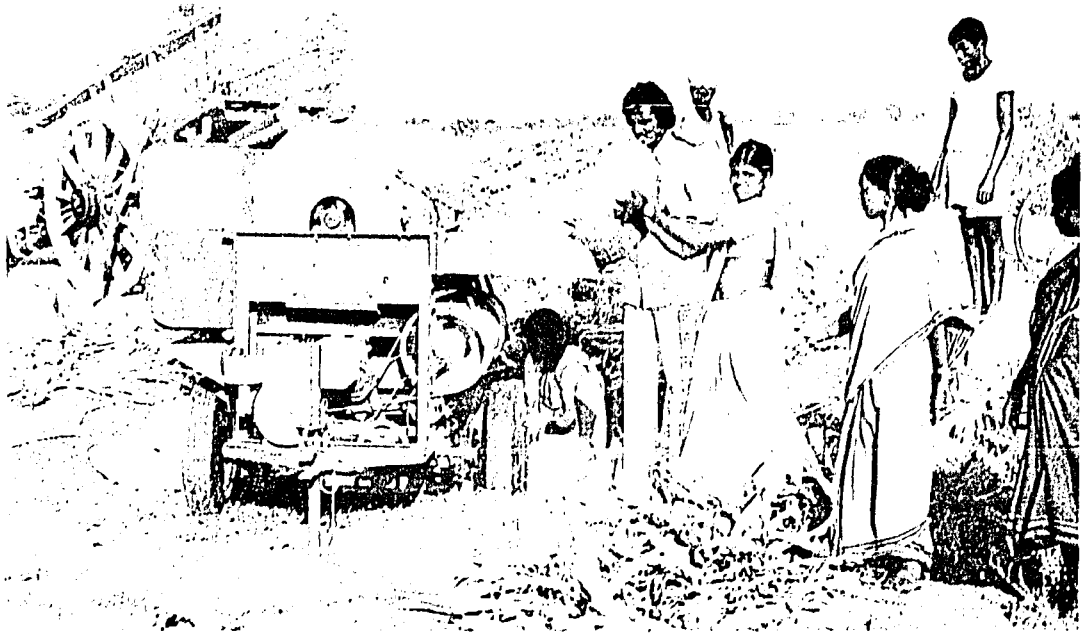
Profitable Cropping on Vertisol Fallows

Data from 5 years of joint research by the Farming Systems Research and Economics Programs at ICRISAT Center were examined to determine technology options for Vertisol fallow regions.

The analysis showed that an improved watershed-based technology involving maize intercropped with pigeonpea can increase profits by about 600% compared with a traditional system based on rainy-season fallow and postrainy-season sorghum and chickpea. This represents a rate of return of 250% on the additional annual expenditure of Rs. 1200/ha (US$ 133) required to implement the improved technol-

Investigations on Vertisol rainy-season fallows have shown that they can be cropped using suitable equipment.





Machine threshing studies have been conducted in Kanzara village, Maharashtra state, India. In areas where labor bottlenecks constrain multiple cropping, machine threshing will allow increased cropping intensity.

ogy. This technology greatly increases the demand for human and bullock labor, and substantially changes the seasonal patterns of their use. Hence landless and small farm families who depend heavily on wage labor for their sustenance can share in increased income streams generated from this technology.

These and other analyses are providing guidance and support for ICRISAT's increased collaborative on-farm verification research in pilot projects in the Vertisol assured rainfall zones of India.

Impact of Machine Threshing

A study was made on the prospects for and the effects of the introduction of machine threshing in Kanzara village in the state of Maharashtra, in India. The results showed that introduction of machine threshers did not significantly increase cropping intensity nor displace labor. The diversified cropping pattern, as found in most SAT villages, limits the scope for and conditions the impact of mechanical threshing technologies in SAT India. However, in areas with a limited crop diversity where labor bottlenecks could constrain multiple cropping, machine threshing could play a role in allowing increased cropping intensity.

Only a few machines per village are economically feasible at the present levels of cereal production in SAT India and they would not lead to competitive pricing. Under these conditions, it is therefore questionable whether potential benefits from reduced costs due to new threshing technologies will be passed on to producers and consumers.

Wells and Group Organization

Systems governing shared ownership of open dug wells in two Indian VLS villages, Aurepalle and Shirapur, were studied. At the time of the investigation, the wells were the primary source of irrigation in these villages.

The findings of the study support the view that farmers follow simple, rigid rules when they own and operate wells in common. This suggests that, for joint ownership and their use to be successful, the operation of runoff ponds on small watersheds has to be economically rewarding, very simple, and predictable.

ICRISAT has studied shared ownership of village wells. The farmers follow simple rigid usage rules because of the resulting financial rewards.

Risk and Genotype Selection

The Program developed a method to evaluate genotype performance in multilocation and multiyear trials. The method was based on a distinction between adaptability and stability. When the yield of a genotype at a given location varies little from year to year, the genotype is said to be stable. If its yield on average over years varies little across locations, the genotype is termed adaptable.

The method was used on a large experimental data set for sorghum in India. It was found that the higher risk associated with higher yielding cultivars was well within the risk tolerance of farmers as revealed in earlier studies. Also, yield-based ranking of sorghum cultivars coincided well with a risk preference-based ranking.

Economic Potential of Water Harvesting

A simulation model was used to assess the economic potential of harvesting excess runoff from rainfall into small upland tanks or reservoirs for supplementary irrigation of rainy-season sorghum during periods of moisture stress for the Hyderabad and Sholapur regions in India.

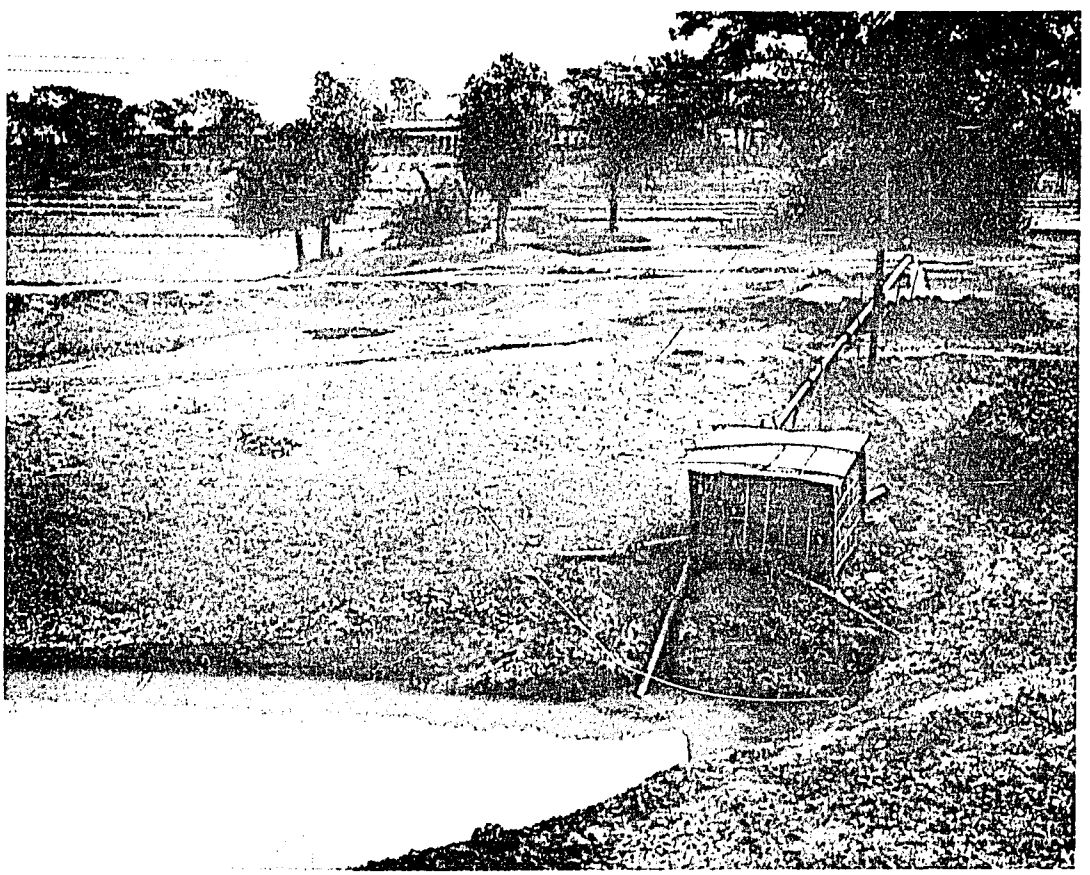
The results suggest that it will be difficult to justify water harvesting and supplementary irrigation for rainy-season, low-value upland crops such as sorghum. Consideration will have to be given to changing the cropping patterns along with the introduction of water harvesting technology. Then, the water could be used more frequently than would otherwise be the case if it were kept only for "life-saving" irrigations of traditional upland crops.

Other Highlights

- Lack of capital and extension and management expertise required to improve farmers' technical efficiency were found to be the major reasons for large gaps between feasible farm yields and those being currently obtained. Capital constraints explained more than 50% of the gap.

- Risk aversion by farmers is only of significance in explaining output gaps on small farms. Even then it is less important than capital and technical efficiency constraints.

Excess runoff from rainfall is conserved in small upland tanks. An irrigation pump permits supplementary irrigation during moisture stress periods. Simulation studies are under way to assess the economics of such use of water.

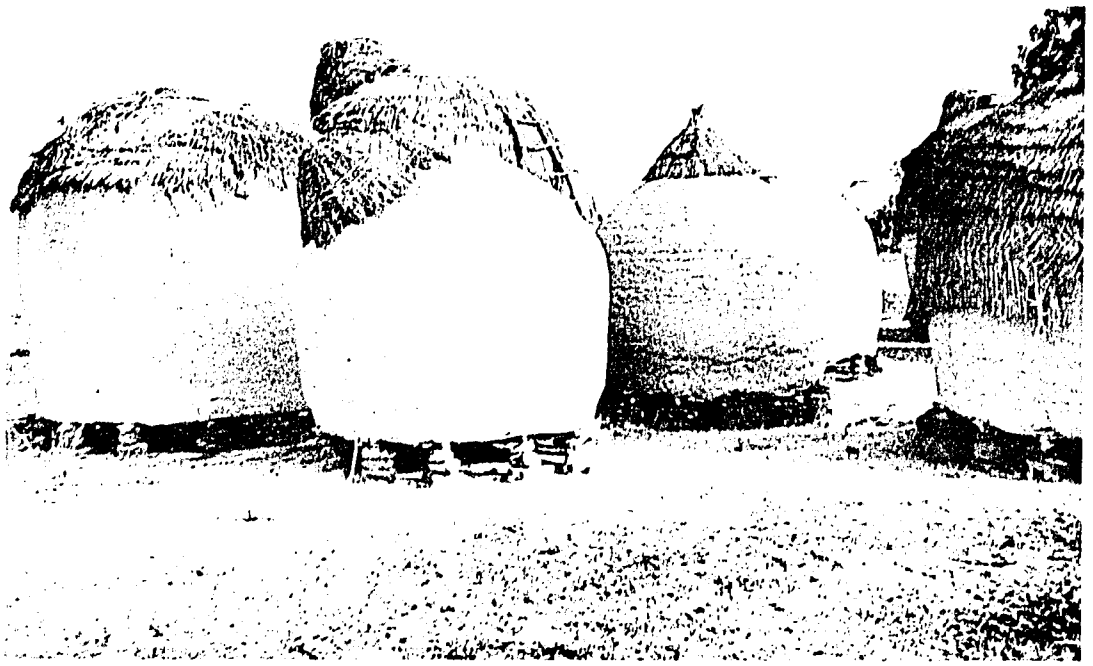


International Cooperation

ICRISAT's international cooperative programs are aimed at strengthening national research without duplicating or competing with it. The Institute has the capability to assist regional and national programs in various ways including providing early-generation breeding material and exchanging germplasm, training, promoting scientific interaction through conferences, workshops, and seminars, etc., enabling ICRISAT scientists to work with national and regional program staff on crop improvement, farming systems, and economics.

By subject matter, ICRISAT is involved in international cooperative research in sorghum, pearl millet, chickpea, groundnut, farming systems, economics, and genetic resources. By region, there is cooperative

An ICRISAT scientist in West Africa surveying a thin stand of traditional millet following sparse germination. ICRISAT is developing new pearl millet lines that substantially outperform local varieties.



Grain stores in West Africa for crops such as [illegible] and millet

activity in the Indian subcontinent, western and southern Africa, southeast Asia, west Asia, Mexico, Brazil, and Central America.

Strong ties have been established with organizations such as ICARDA in Syria, CIMMYT in Mexico, ICIPE in Kenya, and universities and research establishments in India, Thailand, Australia, the UK, the USA, Canada, West Germany, and Japan.

In 1981, a substantial amount of research was conducted in Africa; the chickpea studies in conjunction with ICARDA and our sorghum program in Mexico made considerable progress; our cooperative work in India was also very active.

Upper Volta

An ICRISAT team is stationed at Kamboinse, Upper Volta, which is the main agricultural research station of the Voltaic Ministry for Higher Education and Research. Research

ICRISAT's client group in Sahelian Africa: rural people of limited means who live at subsistence levels.

subjects comprise economics and the improvement of farming systems, sorghum, pearl millet, and their resistance against the parasitic weed, *Striga*.

Screening of local sorghum varieties has identified elite long duration lines for yield testing and crossing with improved cultivars. A further highlight was the testing of cultivar E35-1 on 130 farms throughout its zone of adaptation (i.e., within the area of 600-850 mm annual rainfall). Under supervised cultural operations in Kamboinse village, E35-1 had an average yield of 2165 kg/ha; in other locations with reduced supervision and where drought often delayed planting its mean yield was 1025 kg/ha.

Breeding work on resistance to *Striga* infestation in sorghum and millet was continued. In sorghum, the resistance of N13, IS 8686, and SPV 103 was confirmed in a multi-location trial in Upper Volta, Mali, Ghana, Nigeria, Sudan, Ethiopia, and Cameroon. Several new sources of resistance—Najjadh, IS 2862, and IS 9830—were detected.

Over 800 germplasm lines of pearl millet were evaluated for disease resistance, head emergence, seedling vigor, and tillering. A set of Togolese lines showed good yield and disease-resistance characteristics. Trials of synthetics from ICRISAT Center (varieties produced by crossing a number of inbred lines) revealed several high-yielding disease-free entries.

A number of millet lines of African origin were identified as less susceptible to *Striga*. Under combined *Striga* and drought stress in northern Upper Volta, lines P 2671 and P 2950 showed outstanding resistance to *Striga*.

After 5 years of testing in a "sick plot" at Kamboinse, four Ex-Bornu type millet lines—700251, 700516, 700651, and 700792—

have consistently shown low levels of downy mildew infection, particularly line 700651. Low-susceptible lines of Mali and Upper Volta origin have also been identified.

Reconnaissance surveys to obtain a description of different local farming systems were conducted in villages representative of the agroclimatic regions of Upper Volta. Sites for village level studies have been chosen from the data collected and work has started.

Niger

The initial development of ICRISAT's Sahelian Center in a typical millet growing area near Niamey was commenced in late 1981. The land assigned to ICRISAT by the Government of Niger was surveyed for fencing and sites were explored for water.

The Center will service the needs of countries in West Africa in respect of research on pearl millet and groundnut improvement, farming systems, economics, transfer of technology, cooperative research with national programs, and training of scientists.

Our pearl millet breeding program at the INRAN Research Center in Maradi commenced 3 years ago. Four promising varieties—i.e., ITV 8001, ITV 8002, ITV 8003, and ITV 8004—have been selected from the breeding program and included in the African Regional Trial for testing across countries.

Mali

Testing of sorghum collected in Mali has revealed a rich source of genetic material for future sorghum improvement work. The findings include identification of cultivars with wide adaptation, good yielding ability, resistance to *Striga*, and good grain quality.

Results from F_1 hybrids involving Malian male parents and a male sterile line showed outstanding performances in seedling and plant vigor, drought tolerance, and grain yield. This indicates that Malian sorghums can be exploited in hybrid breeding programs.

Nigeria

In yield trials, Nigerian Composite and Ex-Bornu pearl millet yielded 940 kg/ha and 667 kg/ha, respectively, more than a local farm variety, indicating the advantage that farmers could obtain by adopting improved varieties.

When pearl millet materials were grown in the downy mildew "sick plot," 33 entries showed high resistance to this disease. In other disease trials, four local collections showed high resistance to ergot and downy mildew; a large number of entries from international trials and of local origin showed smut resistance.

In sorghum pathology studies, 15 local cultivars were found with resistance to the major leaf spot diseases, i.e., grey leaf spot, blight, and anthracnose. When 283 lines were re-evaluated for sorghum downy mildew resistance, 24 were found to be also resistant to major leaf spot diseases and major insect pests.

Sudan

The highlight of the year was the release for general cultivation of Serere Composite-2 millet by the Variety Release Committee of Sudan. It has been given the name Ugandi. In the past 3 years, it had consistently outperformed the local variety Kordofani, in both favorable and unfavorable seasons in Sudan.

In multilocational national trials, millet cultivars ICMS 7818, ICMS 7703, and IVS A76 consistently outperformed local varieties.

At Wad Medani, very good results were obtained among 25 entries in the ICRISAT Sorghum Hybrids Yield Trial-I. There was excellent crop expression—very impressive head size, well-filled heads, and good grain

quality. The three highest-yielding hybrids were 296A x A-964 (5386 kg/ha), 2077 x A-717 (5302 kg/ha), and 2077A x MR-737 (5177 kg/ha).

Mexico

An ICRISAT breeder posted at CIMMYT in Mexico is breeding sorghums with cold tolerance for use in the high altitude areas of Mexico and Central America. Varieties are also being developed for use at lower altitudes; four varieties are being extensively tested in Venezuela.

This research work is exposing the potential for the use of sorghum as a food for small farmers on marginal lands and its importance as a possible admixture in flour for making tortillas.

West Asia

ICRISAT has a full-time breeder and a pathologist headquartered in Aleppo with ICARDA, where cooperative research is being conducted on chickpea.

The major objective is to develop cold-tolerant cultivars with resistance to *Ascochyta* blight for winter sowing, which has a substantial yield advantage over spring sowing.

In the Chickpea International Yield Trial (Winter), mean seed yields were 60% higher than those of spring-sown cultivars. They exceeded 3 tonnes/ha at two locations, which indicates the potential for winter sowing in the Mediterranean region.

Screening at ICARDA for *Ascochyta* blight has revealed resistance in 22 kabuli and 131 desi types. The program is breeding tall types for mechanical harvesting and increased seed size, i.e., 40 g/100 seeds, for southern Europe, and South and Central America.

The protein content of germplasm accessions has been found to range from 16.0 to 24.8%.

Transfer of Technology

The Training Program at ICRISAT is vitally involved in the transfer of technology processes. It has five types of training at ICRISAT Center—in-service training for young scientific and extension staff from the SAT; in-service fellow programs; research scholarships; research fellowships; and international interns who have recently received Ph.D. degrees from agricultural universities in donor countries.

In 1981, 79 persons from 26 countries completed the in-service training course; 14 scientists completed the research scholars' program; and 10 research fellows and 2 international interns finished their programs. Since 1974, more than 500 persons have completed one of these training courses.

Nine workshops, conferences, and specialist meetings were hosted by ICRISAT. Of particular importance were conferences on Sorghum Grain Quality, Sorghum in the Eighties, and *Heliothis* Management. They enabled scientists and agricultural specialists from all over the world to discuss research findings. These specialists were among 8700 visitors to ICRISAT Center during 1981. As usual, large numbers of farmers (2500) visited the Center to inspect the crops and examine first hand how solutions to their problems are being found.

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