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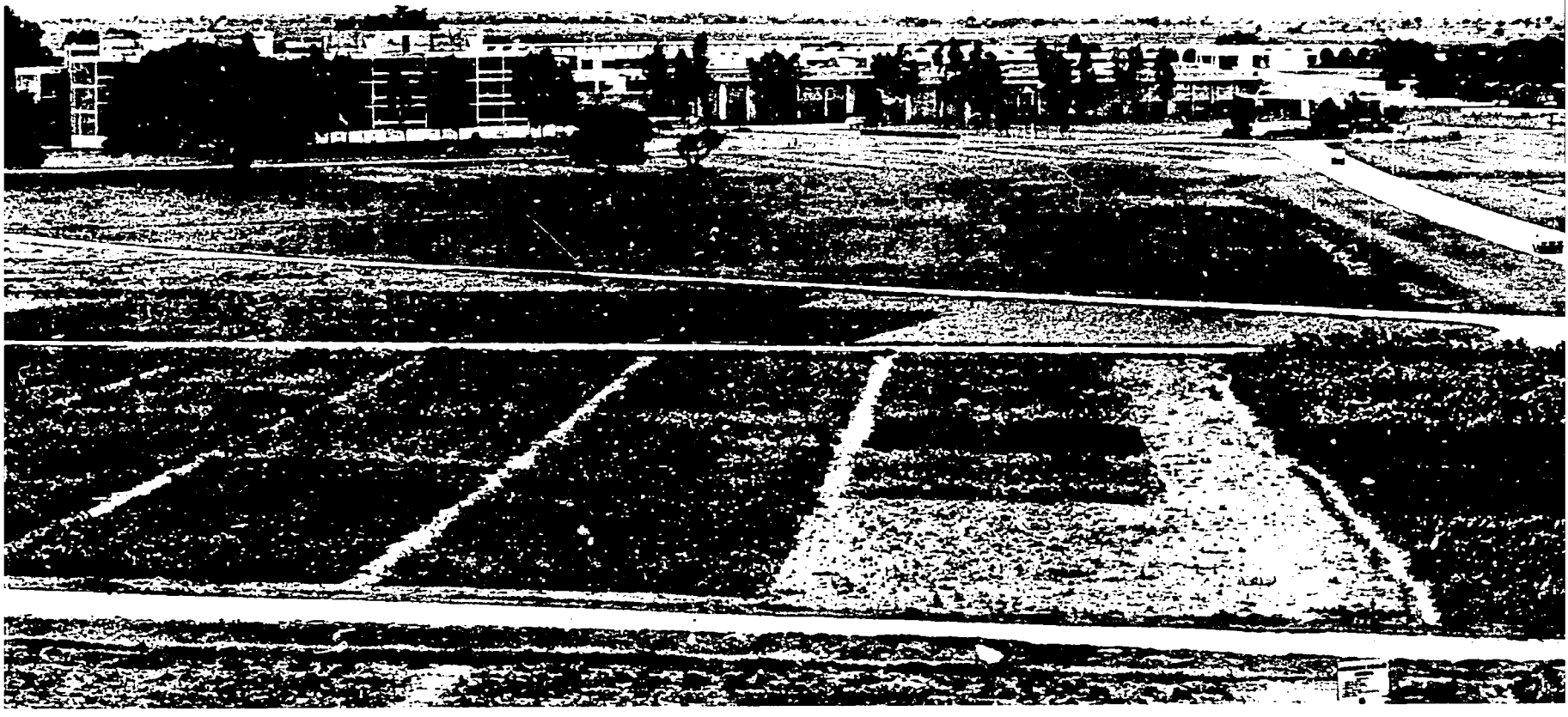
ICRISAT
Research Highlights
1979

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



ICRISAT Center, Patancheru, India. The Institute's new facilities were completed and inaugurated in 1979.

Introduction

ICRISAT is one of 13 international centers in a worldwide research network devoted to improving food production in less developed countries. ICRISAT's mandate is to improve the yield, stability, and food quality of five crops basic to life in the semi-arid tropics (SAT) and to develop farming systems that will make maximum use of the human and animal resources and the limited rainfall of the region.

The seasonally dry semi-arid tropics are spread over nearly 20 million square kilometers and cover all or parts of 49 nations on five continents. They include much of India, parts of Southeast Asia and the Middle East, two wide belts of Africa, areas of South America, and much of Mexico and Central America.

The SAT is a harsh region of limited, erratic rainfall and nutrient-poor soils; it is populated by more than 600 million people, most of them living at subsistence levels and dependent upon the limited production of small farms for their food. In these areas, farm practices remain essentially as they have been for centuries.

The crops researched by ICRISAT are sorghum and pearl millet—two of the major cereals in the SAT—and pigeonpea, chickpea, and groundnut, the most important food legumes of the region. Groundnut, rich in oil as well as protein, is the only one of these that is a major cash crop for the SAT farmer. The four others are all primarily subsistence food crops; over half the total production of each is consumed on the farms where it is produced. The SAT produces more than one-half of the world's sorghum, at least 80% of the pearl millet, 90% of the chickpea, 96% of the pigeonpea, and 67% of the groundnut. But yields of all of these crops are low by developed-country standards and in comparison with their potential yield in the SAT.

ICRISAT scientists work in interdisciplinary teams in their efforts to develop new high-yielding cultivars (cultivated varieties and hybrids) that will perform well under near-drought conditions and low or no inputs of fertilizer

The Semi-Arid Tropics (shown in brown)

and pesticides. A major effort is made to develop cultivars inherently resistant to the major pests and diseases that damage or destroy crops in the SAT.

The crop improvement teams consist of plant breeders, entomologists, plant pathologists, plant physiologists, botanists, microbiologists, and biochemists. They draw on the genetic resources of the Institute's germplasm bank for the five crops, a collection that has so far supplied over 110 000 samples of breeding material to scientists all over the world.

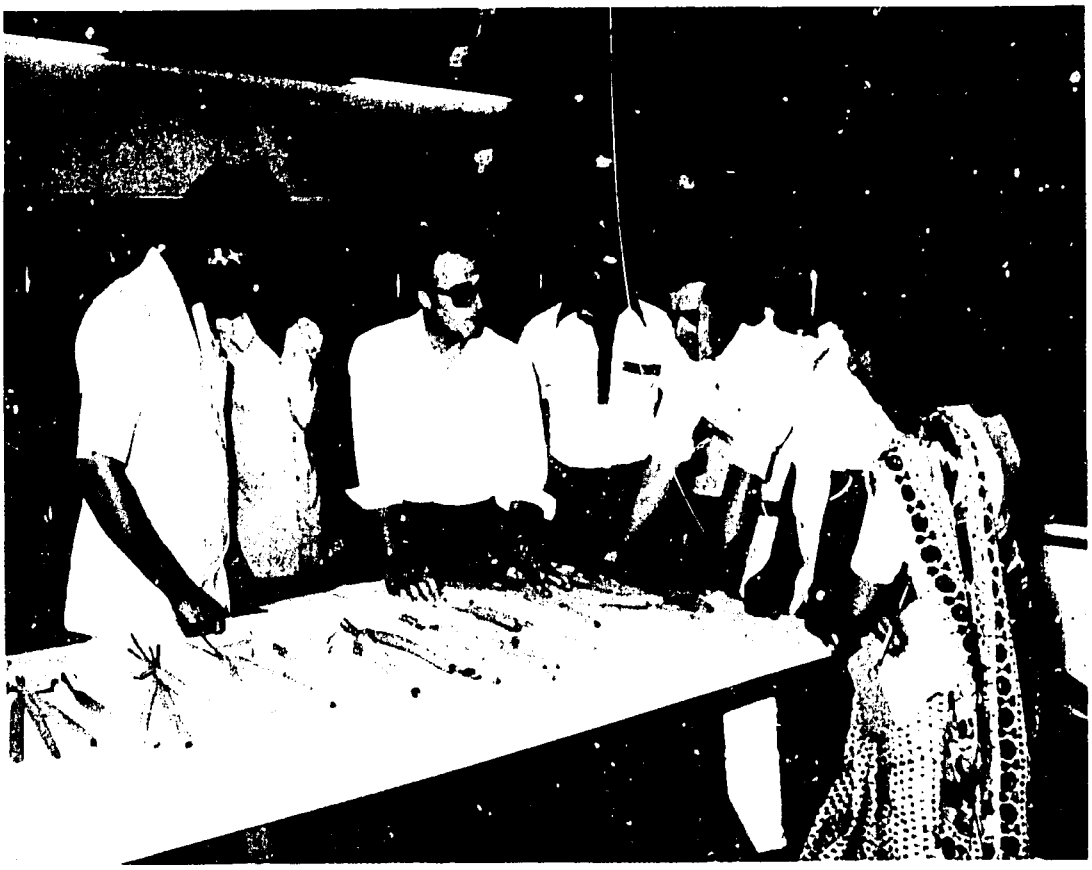
Agronomists, agricultural engineers, land and water management specialists, agroclimatologists, soil physicists, and soil chemists work together to develop improved farming systems and cropping patterns appropriate for small farms of the SAT. ICRISAT economists and social anthropologists work closely with Farming Systems scientists to evaluate these technologies and relate them to actual conditions in the villages.

Since its creation in 1972, ICRISAT has made significant progress in all areas of its mandate. This report highlights some of the more important achievements in the crop year 1 June 1978 to 31 May 1979; additional details can be found in the ICRISAT Annual Report for that period. In a few instances we have gone beyond the end of the crop year to report major research achievements recorded later in 1979, such as the identification of new pearl millet lines that combine resistance to all three of the yield-reducing diseases of downy mildew, ergot, and smut. In those cases additional details may be obtained from the concerned program.

Major activities at ICRISAT in 1979, aside from progress in individual research programs, included completion of most of the new buildings planned at ICRISAT Center and the formal inauguration of this headquarters complex on the research farm at Patancheru, 25 kilometers northwest of Hyderabad, India. These facilities enable our headquarters staff, formerly housed in 20 separate buildings in Hyderabad and Patancheru, to work together in modern facilities at a single location and thus facilitate communication and research.

Also during the year, the cereals program was divided into separate research programs for sorghum and millet, each with its own interdisciplinary team. And the various activities for the collection, maintenance, description, and distribution of the germplasm for ICRISAT's mandate crops were con-

A village housewife in India makes chapatis from sorghum flour. Sorghum is a staple in the diet of millions of people in the SAT.



ICRISAT scientists receive African pearl millet germplasm from representative of the French research organization ORSTOM for Institute's genetic resources collection.

solidated into a single new Genetic Resources Unit. More than 58 000 germplasm accessions of ICRISAT's mandate crops and their wild relatives have been assembled in the international gene bank being developed by this new unit to carry out ICRISAT's responsibility for the world collection of the five crops. This collection, when complete, will comprise all the known varieties and cultivars of these crops for the use of future generations.

Sorghum

Sorghum is one of the world's important cereals and a major staple in the diets of the people of the semi-arid tropics. It is the leading cereal in Africa and is next in importance to rice and wheat in India. In some areas of Central America, Latin America, and Africa that are only marginally suitable for maize production, farmers have started growing sorghum in recent years as an insurance crop in the event of failure of maize crops. As a human food, sorghum is ground into flour and made into porridges or unleavened bread. The grain is also used as feed for animals, particularly in the Americas, and for processing into beer and other local beverages in Africa. The sorghum stalk provides fodder, fuel, shelter, sugar, and syrup.

A high-yielding line of sorghum at ICRISAT Center. Some heads are bagged to prevent cross pollination so that the seeds that develop will be true to type.

ICRISAT scientists examine the grain of an improved sorghum line resistant to grain mold.

Sorghum is a hardy and dependable crop that will grow well under adverse conditions. It thus can play a major role in increasing food production in the semi-arid tropics. Present on-farm yields of sorghum average only 600 to 700 kilograms per hectare for SAT areas of Africa and India, compared with about 1800 kg/ha in areas of Africa outside the SAT and 4000 kg/ha for areas of the USA that produce the crop. At ICRISAT Center, sorghum yields of 4900 kg/ha have been obtained under high fertilizer application and more than 2600 kg/ha with low fertilizer input in operational field trials. Although these research station conditions and scientific monitoring do not exist on farmers' fields, the results show that there is potential for greatly increasing sorghum yields throughout the SAT.

Important advances were made in 1979 in ICRISAT's efforts to improve sorghum yield, stability of production, and food quality of the grain.

High-Yielding Sorghum Lines

High-yielding lines of superior sorghum material from ICRISAT are now beginning to make substantial contributions to breeding efforts throughout the world. In the 1978–79 crop year more than 130 advanced lines with higher grain yield potential were distributed to breeders in 20 countries of the SAT for direct utilization in yield trials and advanced observation nurseries. Subsequently breeders will select the best lines in their regions to use for development of new superior cultivars for local purposes. In addition, 75 lines with resistance to either grain mold, shoot fly, *Striga*, or stem borer were sent to cooperators throughout the SAT for use in their breeding programs.

Among our early-maturing advanced lines (flowering in less than 60 days at ICRISAT Center), Diallel Pop-7 was outstanding at Nazareth in Ethiopia (6950 kg/ha yield) and at Rahuri in India (6690 kg/ha yield).

In multilocational tests of medium to medium-late maturity lines (flowering after 60 days), the ICRISAT entry that gave the best mean performance yielded 3340 kg/ha. Another of our lines performed well in West Africa, ranking first in Upper Volta, Mali, and Ghana.

Pest- and disease-resistant lines from ICRISAT also performed very well at several locations. At 18 locations in 12 countries, they were generally less susceptible to leaf diseases than local sorghum lines. Some of the lines did exceedingly well under low

rainfall conditions in Botswana. In Mali, an ICRISAT line yielded 1300 kg/ha more than the "check"—local or other material used for comparison. In Upper Volta and Sudan also, our lines performed much better than the local checks.

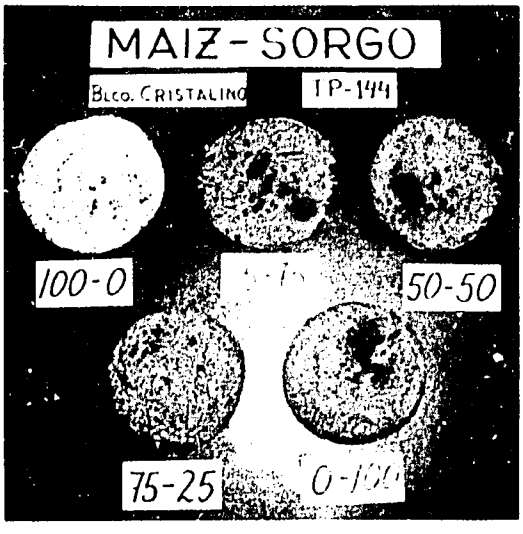
Good Food Quality

Higher yielding sorghum varieties sometimes are not acceptable to farmers because the lines lack the locally preferred taste or quality of traditional popular varieties. Scientists thus are constantly searching for or seeking to create lines that will not only produce higher yields and carry resistance to disease and pests, but also will have the preferred food quality characteristics. ICRISAT's continuing search for food-quality sorghums resistant to grain mold paid off this year with development of seven lines possessing good grain quality that can be grown in the wet season. Prior to this, most mold resistant lines had poor grain quality. In addition to their high-yield potential, these seven lines are equal to the best local dry-season variety in India for making chapati, an unleavened bread. This capability to achieve dry-season quality in wet-season sorghum crops should lead to development of high-yielding lines more acceptable to consumers.

In Africa, our breeders are trying to identify agronomically superior sorghum lines with acceptable porridge quality (for making *teau, ugali,* etc.). One such line, E35-1, is ready for introduction on farmers' fields after successful research station testing.

In Mexico and other countries of Central America where tortillas made from maize are a traditional popular food, sorghum lines suitable for making tortillas have been identified from ICRISAT material and are winning increasing acceptance. This is particularly true in marginal maize-producing dry areas.

ICRISAT sorghum lines suitable for tortillas are combined with the traditional staple, maize, for making this popular food in Central America. Photo shows tortillas of various compositions ranging from 100% maize (upper left) to 100% sorghum (lower right).



Resistance to Shoot Fly

Shoot fly is a serious insect pest of the sorghum plant. It feeds on the central shoot and kills it, causing great losses in yield.

ICRISAT scientists are constantly searching for sources of resistance to this pest. It has been found that cultivars having trichomes (microscopic hairs) on the undersurface of the leaf are generally more resistant to shoot fly. Evidence indicates that the presence of trichomes leads to a reduction in the amount of egg-laying on the leaf and offers mechanical resistance to the migration of larvae to other parts of the plant. Further, it has been found that plants with both trichomed leaves and glossy upper sur-

faces are more resistant to shoot fly than those without these traits. There is a strong possibility that incorporation of both these traits (trichomed and glossy leaf surfaces) into sorghum breeding lines will result in an improvement of shoot fly resistance.

During the 1979 summer season (March sowing) over 2200 entries from the resistance breeding program were planted at Hissar, in northern India. Shoot fly attack was severe; each plant had 15 to 20 eggs. In this nursery, 17 of our entries had less than 30% damage, while a local check had 50% damage.

We are conducting collaborative studies with the International Center of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya, to learn more about shoot fly and its larval migrations. These studies will assist us in reducing shoot fly damage.

A sorghum line resistant to shoot fly stands in sharp contrast to a susceptible line (examined by scientist) in test plot at ICRISAT.

Rearing Stem Borer on Artificial Diets

The spotted stem borer, *Chilo partellus*, is an important pest of sorghum in India and in the lowland areas of East Africa. In order to screen sorghum lines for stem borer resistance, availability of adequate populations of the insect is essential. We established a stem borer rearing laboratory at ICRISAT Center this year, and developed an artificial diet on which the pest is being successfully reared (80 to 90 adults recovered per 100 eggs). We are now able to produce the large populations needed to infest 3 hectares of material per season with sufficient pest pressure to single out resistant lines. Using these stem borers, we have identified 1130 lines from the world collection for further screening for resistance to this pest.

The stem borer (Chilo partellus) *causes heavy damage to the sorghum plant.*

Other Highlights

- Some 30 agronomically good lines were identified for their resistance to head bug, *Calocoris angustatus*. One variety was a frequent parent in these selections.

- It was found for the third year of international testing that the variety QL3 remained immune to sorghum downy mildew, and three others averaged less than 10% incidence of the disease.

- A technique was developed for observing response to moisture stress in the seedling stage of sorghum growth. This will help in our breeding program by enabling early identification of resistance to drought.

- Eight sorghum cultivars were found to stimulate a high degree of nitrogenase activity by soil bacteria in both rainy and postrainy seasons. Cultivars that stimulate more nitrogen-fixing activity by bacteria in their root zones will produce greater sorghum yields without increased nitrogen applications.

A laboratory technician places butter paper beds for egg laying by sorghum stem borer in artificial rearing cage at ICRISAT.

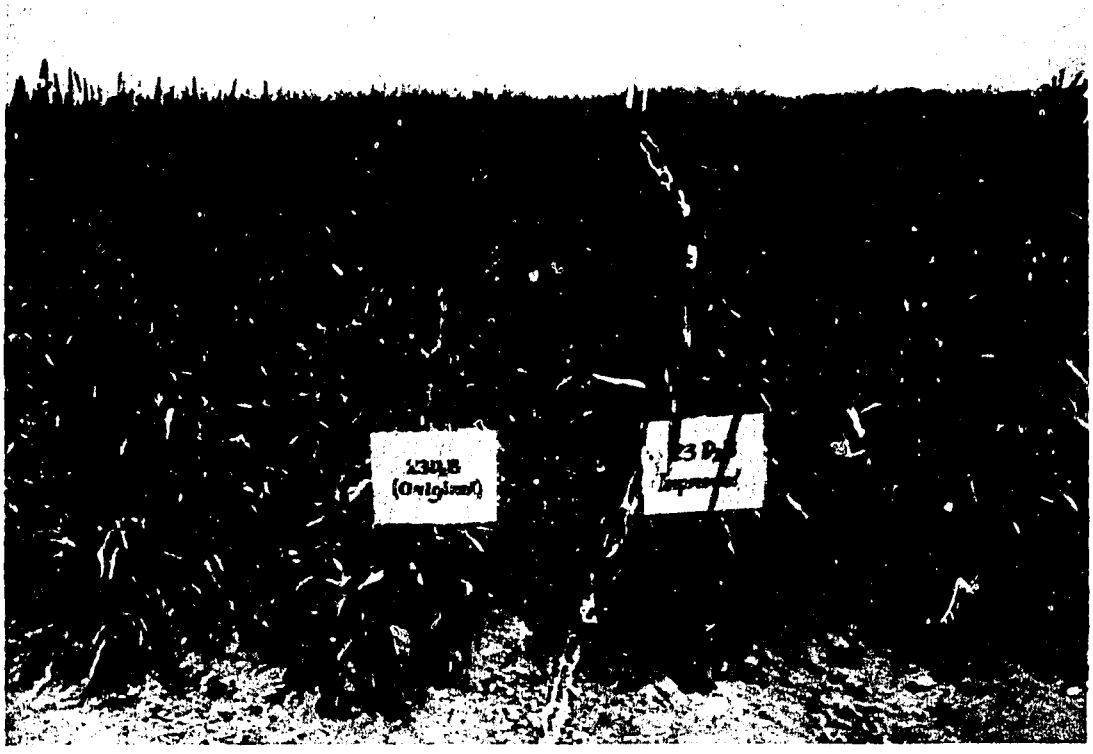
Pearl Millet

Millets rank seventh in world cereal production. They are used as animal feed or forage in the more developed countries, but in vast areas of the SAT they are the principal cereal—the main source of calories—for millions of people.

The Pearl Millet Improvement Program at ICRISAT, formerly combined with sorghum in a Cereals Improvement Program, was given an expanded staff and independent status in 1979. That development has accelerated efforts to breed superior pearl millet varieties with higher yield and improved resistance to drought, diseases, and low soil fertility.

ICRISAT's pearl millet research is considerably strengthened by its scientists posted in Africa, who are working with national scientists there. Pearl millet originated in sub-Saharan West Africa, and it is in this

This high-yielding variety of pearl millet (WC–C75) is resistant to downy mildew and is being multiplied in pre-release Indian national trials. It is likely to become the first ICRISAT-bred product to be adopted on farmers' fields in India.



The pearl millet line at right, highly resistant to downy mildew, was developed from the highly susceptible line at left.

region that its richest sources of genetic diversity occur. It was from Africa that the Institute obtained pearl millets that contained the genes needed to breed plants resistant to downy mildew and ergot, two major destroyers of the crop in India.

Development and Testing of New Genotypes

Rapid genetic improvement depends on the availability of effective breeding and selection techniques. In addition to using the conventional variety-cross method to obtain improved genetic combinations from relatively homogeneous lines, the Pearl Millet Program has successfully used recurrent selection in genetically variable populations (composites). Several cycles of this process of reselection and recombination from composites exhibiting the desired traits have produced a steady increase in grain yield combined with significant reduction in downy mildew susceptibility. Moreover the plants are shorter and, through photosynthesis, put proportionately more material into grain. They are also less likely to suffer damage from lodging. In 1978, experimental varieties derived from recurrent selection of composites were among the top-yielding entries in the All India Coordinated Millet Improvement Project trials, and one (WC–C75) was promoted to the pre-release Indian national minikit tests for 1979.

Multilocational trials are an essential tool in identifying the most useful material at all stages of genetic improvement. ICRISAT has developed an international network of field trials for evaluation of its improved genetic products and contributes superior material emerging from this network to national program testing systems.

ICRISAT's 1978 Advanced Pearl Millet Synthetics Trial identified one line as the top-yielding entry in four Indian and two African locations, with less than 5% incidence of downy mildew across all locations. It combined this high level of resistance with yields ranging up to 3090 kg/ha in India and 2350 kg/ha in Africa. In the 1978 Advanced Pearl Millet Hybrid Trial, four hybrids performed well in India with yields ranging from 2780 to 3110 kg/ha, while in Africa four other hybrids were the best, with yields from 2720 to 2980 kg/ha.

Male Sterility

When two inbred lines are crossed, the resultant hybrids can give substantially better yields. For commercial production of hybrid seeds, one of the two inbred lines used must be male sterile—producing no pollen, so that all its plants are pollinated by the other line grown alongside. However, the male-sterile lines that were initially available in pearl millet were highly susceptible to downy mildew and were from a narrow genetic base. In order to help millet breeders capitalize on the potential advantages of hybrids, the ICRISAT Millet Program initiated a project to improve and diversify male sterile lines.

Our work involves conventional backcrossing to introduce the genetic sterility factor into useful inbreds, the reselection of existing but unusable seed parents to improve their defects, and the use of irradiation to induce downy mildew resistance in highly susceptible but otherwise good male sterile lines. This last activity has resulted in the production of a highly DM-resistant version of a valuable seed parent that had been abandoned earlier because of its extreme downy mildew susceptibility.

Disease Control

Downy Mildew (DM)

This most widespread and devastating pearl millet disease has received major attention in the Pearl Millet Improvement Program. Integrated breeding and pathology activities carried out in the DM nursery for two seasons per year for 3 years have resulted in the development of a high level of DM resistance in most of ICRISAT's pearl millet breeding materials. We consider this one of the Program's most important achievements since its inception.

More than 7000 pearl millet breeding lines, test hybrids, experimental varieties, and germplasm entries were tested for resistance in a DM-screening nursery at ICRISAT in the 1978 rainy season. Of the 300 germplasm entries retested in the postrainy season 1978–79, 84 had less than 10% DM, a very low incidence of the disease.

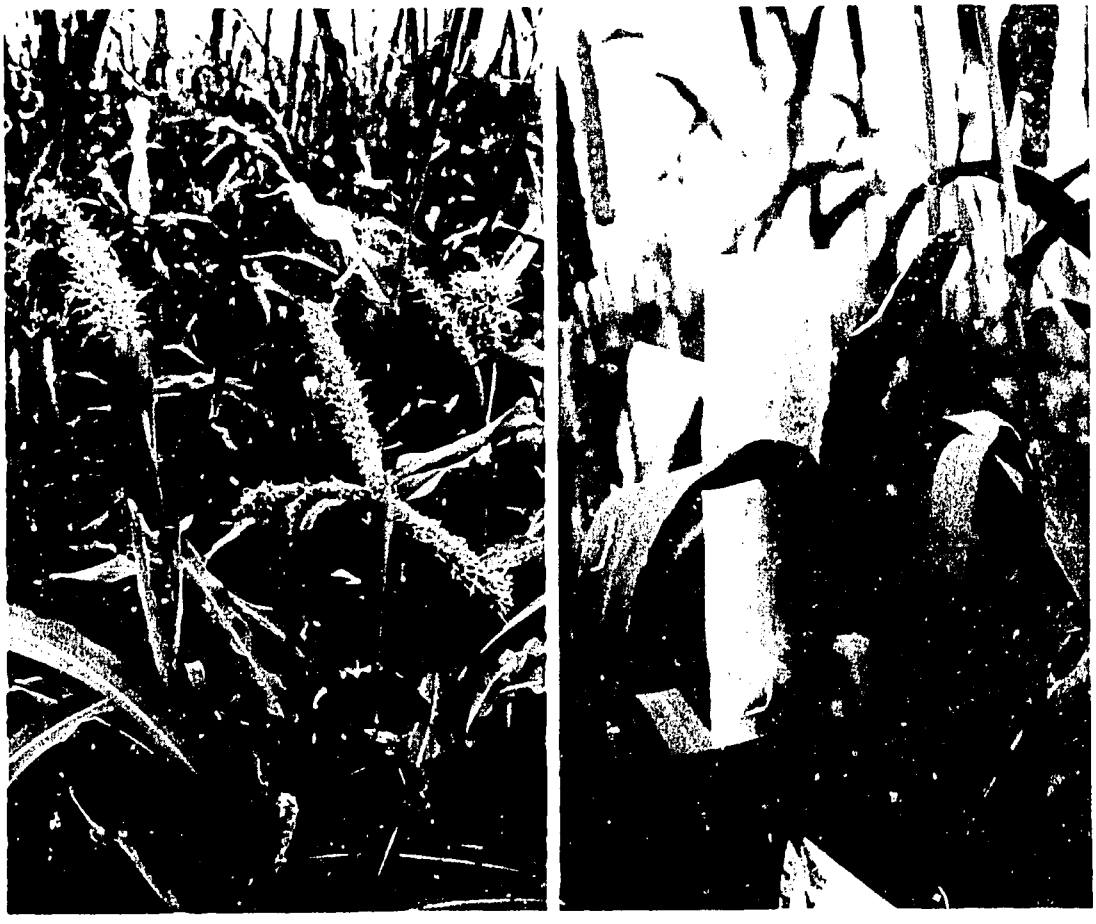
The stability of DM resistance was examined through cooperative multilocational testing, with the participation of scientists in national and regional programs in Africa and Asia. In the 150-entry nursery tested in Upper Volta, Nigeria, and India, 16 ICRISAT entries had no more than 10% DM incidence at any location. From this trial 30 entries were chosen to go forward to the 45-entry 1978 trial sent to 27 locations in 10 countries; 42 entries had less than 10% infection across locations. One entry, SDN–503, had no more than 10% infection at any location and has performed well in 3 years of testing.

Ergot

Ergot is a fungal disease that infects the heads of some cereal crops, resulting in yield reduction and in the production of materials highly toxic to people and animals that eat the contaminated products. Next to downy mildew, ergot is the most serious disease of pearl millet hybrids.

In 1979 ICRISAT workers in pearl millet developed for the first time lines with significant levels of ergot resistance, combined with resistance to DM and smut. These are from descendants of crosses made in 1977. More than 1800 materials were tested for ergot resistance at ICRISAT Center during the 1978–79 crop season to select the best materials for several cycles of retesting. In the multilocational evaluation of the 26 best entries identified at the Center in the previous year's tests, eight entries had mean ergot severity of no more than 15% and several of these had desirable agronomic traits.

Downy mildew (left) and ergot are two of the major destructive diseases of pearl millet. ICRISAT scientists have succeeded in combining resistance to both diseases in high-yielding lines.



Nitrogen Fixation

Major emphasis continued to be placed on examining the potential for exploiting nitrogen fixation by various bacteria associated with pearl millet roots. Over several seasons, 13 lines of pearl millet have consistently stimulated nitrogenase activity by bacteria living in their root zone. Cultivars of several minor millets showed even more consistent activity than pearl millet.

This year 34 nitrogen-fixing bacterial cultures isolated from pearl millet roots were identified and several were successfully used in inoculation studies with pearl millet.

One pearl millet hybrid, grown in washed vermiculite with nitrogen-free nutrient solution and inoculated with nitrogen-fixing bacteria, gained 34 milligrams nitrogen per plant in 48 days, and for each pot of five plants there was a nitrogen gain of 211 milligrams. At harvest, nitrogenase activity was associated with the roots, and the vermiculite without roots showed no activity. These

ICRISAT plant breeder examines a pearl millet variety with bristled heads that may have a potential for reducing the effects of attacks by birds, which are a major problem for farmers in parts of Africa.

results suggest the important prospect of developing pearl millet lines capable of obtaining a considerable amount of their nitrogen requirement by biological nitrogen fixation, thus reducing dependence on fertilizer applications.

Other Highlights

- Data gathered over 3 years indicated that, in pearl millet, the relationships between grain yield and protein content and between protein content and seed size are weak. Breeding work is now under way to examine the possibility of selecting simultaneously for increased protein content and grain yield.

- International trials to examine the stability of resistance to downy mildew, ergot, smut, and rust were sent to cooperators in ten countries in Africa and Asia.

- Researchers identified potentially useful alternative control methods for downy mildew by seed dressing with the new systemic fungicide metalaxyl (Ridomil and Apron, Ciba Geigy Ltd.), and for ergot in hybrids by exploiting the protective effect of timely pollination using early-flowering, ergot-resistant varieties.

- Variation in grain yield was found to be closely related to variation in grain number, and studies have been initiated on ways of increasing grain numbers in the pearl millet crop.

Pearl millet crop in background was grown from seed treated with a systemic fungicide; in foreground is plot that was planted with nontreated seed of the same cultivar. Pegs mark the position of infected plants that died and disappeared.

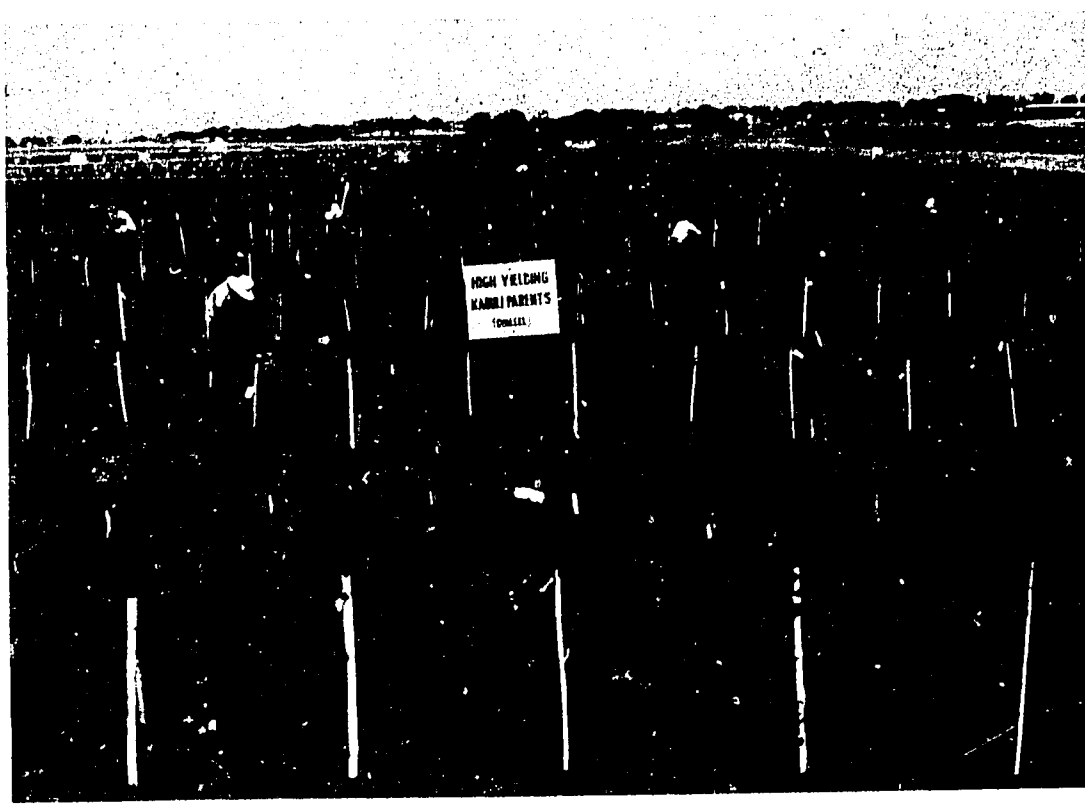
Chickpea

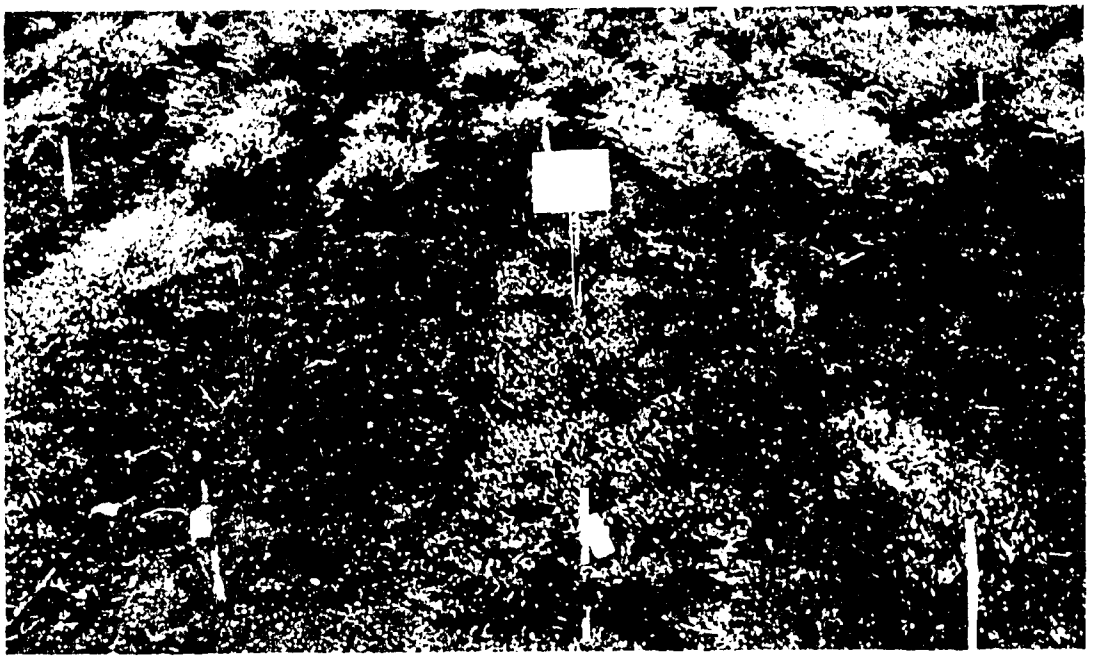
Chickpea is an important grain legume crop of dryland agriculture in Asia, Africa, and Central and South America. It is utilized as human food by millions of persons in areas where crop production is erratic or otherwise limited. It has a high protein content (approximately 20%) and contains some nutrients not found in cereals. When combined with rice, sorghum, millet, or wheat, chickpeas provide an adequate balanced protein-calorie diet.

Yields of this important food crop in the SAT are low, averaging only 700 kg/ha, because of the almost exclusive use of traditional plants, poor management practices, and relegation of the crop to poorer lands. ICRISAT is working to develop high-yielding varieties that will grow well in the harsh conditions of the SAT.

There are two main market types of chickpeas: kabuli (garbanzo), which have smooth, generally large, light-colored grains and are found in the Mediterranean area and Central America; and the desi (garbanzo porquero), which have yellow to black generally smaller grains with a rougher surface than that of kabuli seeds and are grown in Asia and eastern Africa.

A high-yielding, disease-resistant line of chickpea at ICRISAT Center.





The chickpea wilt resistance nursery at ICRISAT Center. The bare patches had wilt-susceptible lines that died and disappeared. Brown plants are mature disease-resistant chickpeas.

In the 1978 79 crop year, ICRISAT's chickpea breeding program for kabuli types was integrated with that of ICARDA in Syria, providing more effective coordination of worldwide efforts to improve this crop.

Chickpea Diseases

Wilt, root rots, stunt, and *Ascochyta* blight are the major diseases that attack chickpea and are a primary target of ICRISAT research. *Ascochyta* blight can entirely wipe out crops in areas experiencing continued cool rainy weather and is the most serious problem of winter plantings in West Asia. In India, wilt and root rot together destroy an average of 10% of chickpea crops per year. Although no figures are available on stunt, we have observed occurrence in farmers' fields ranging from 0 to 90%, with 5% occurrence a common experience.

The cheapest and most effective way to eliminate these diseases is to develop chickpea lines that are resistant to them. ICRISAT has an ambitious program to identify and develop such lines.

Ascochyta Blight

Through our cooperative work with ICARDA we developed several lines resistant to *Ascochyta* blight in Syria. Now for the first time winter sowing is economically feasible there despite the prevalence of *Ascochyta* at that time. This promises to give substantial benefits to farmers by adding another crop each year.

Wilt and Stunt

Of 1800 accessions screened this crop year, 140 have shown great promise in their resistance to wilt, caused by the organism *Fusarium oxysporum* f. sp. *ciceri*. We identified

two lines that exhibit combined resistance to both wilt and stunt. Lentil, pea, and pigeonpea were found to be symptomless carriers (hosts) of the wilt pathogen, a fact important for planning rotation of crops with chickpea. Existence of two strains of *Fusarium oxysporum* f. sp. *ciceri* was established; this will aid in devising an effective means of combating the disease.

Control of Pod Borer in Chickpea

Pod borer, *Heliothis armigera*, is a major cause of damage to chickpea pods. Our studies have confirmed heritable differences among and within the cultivars in susceptibility to pod borer. In ICRISAT's trials this year, one of our pod borer-resistant lines outyielded for the third consecutive year the best local variety, which was used as the check.

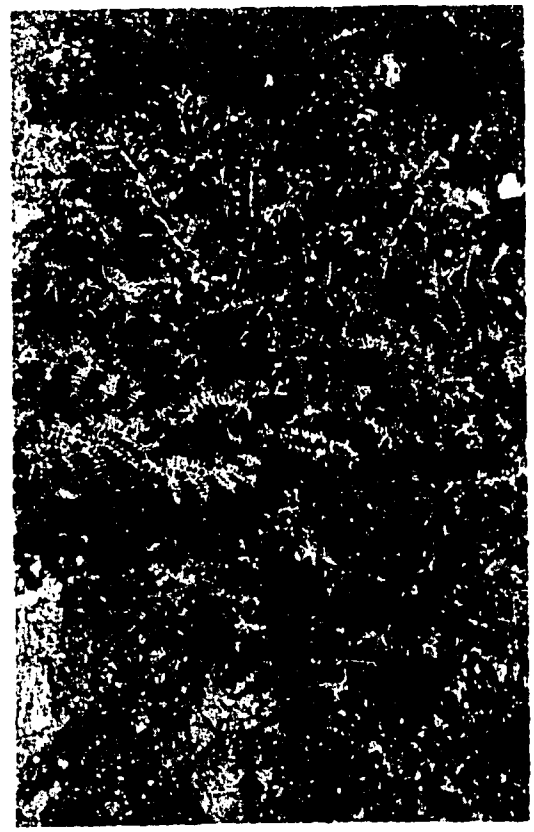
We are studying the mechanisms of resistance to pod borer in chickpea. We believe that differences among cultivars in the quantity and composition of the acid exudate produced by their foliage and pods may account for some of their differences in susceptibility. Pod wall hardness also appears to play a role in this mechanism. Another factor is the ability of the crop to recover from extensive damage inflicted during its vegetative stage, and we are studying differences among cultivars in this regard. Ability to compensate for early damage is of particular interest in the early-maturing cultivars that tend to yield best in the relatively short growing season at Hyderabad.

In laboratory and cage studies on biological control of pod borer, we found that a parasitic fly, *Eucelatoria*, imported to India from the USA, was effective in killing pod borer larvae. The flies, however, could not be established in field cage trials, and we propose to try again with fresh stocks.

Exploiting the Services of *Rhizobium*

Nodules on the roots of chickpeas, and other leguminous plants such as pigeonpeas and groundnuts, are formed by *Rhizobium* bacteria, enabling the plants to take up atmospheric nitrogen. These bacteria occur naturally in the soil, but adding them to the soil can increase the plant's nodulation and thus its nitrogen uptake and yield. Inoculation of seeds with the bacteria is a simple process that costs very little. We are currently investigating ways of making reliable inoculants on a large scale. An important question for research is which *Rhizobium* strains produce best with which cultivars.

The chickpea plant in foreground shows the symptoms of stunt disease; plants in background are stunt-resistant.



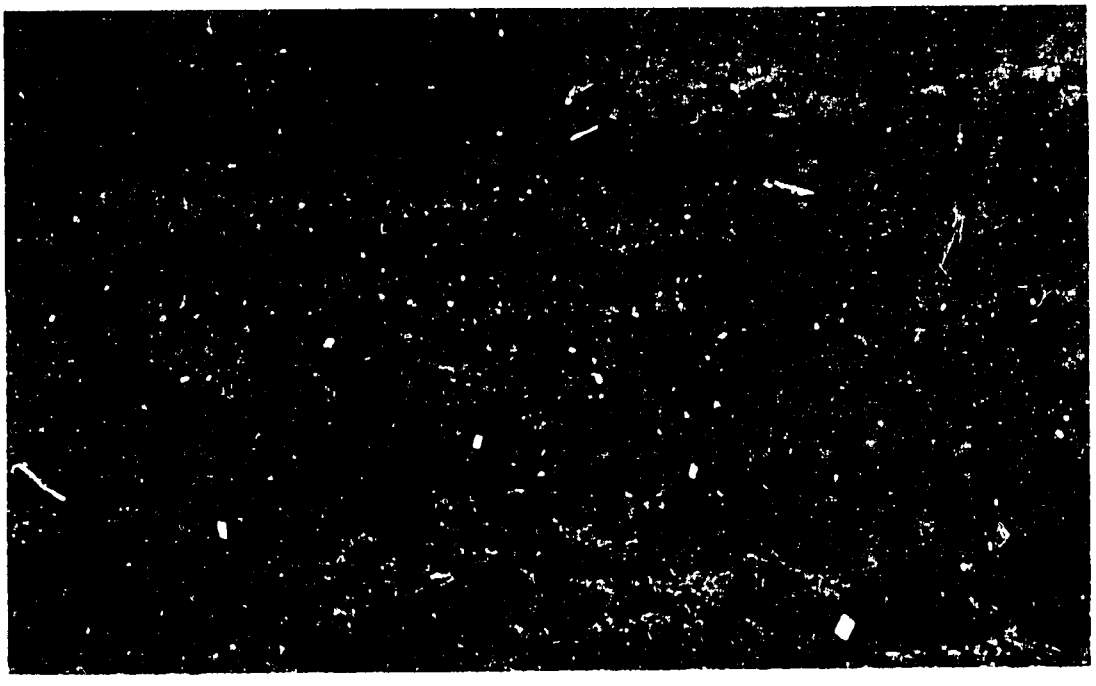
Over 500 authenticated isolates of chickpea *Rhizobium* have been collected from the major chickpea-growing areas of India and six other countries. They are being tested for their nitrogen-fixing ability and tolerance to saline soil conditions.

We have developed a technique for counting chickpea *Rhizobium* in soil, based on the formation of nodules on the crop roots. Using this technique, we have shown that paddy rice cultivation kills these rhizobia in soil, making it advisable to inoculate chickpeas with rhizobia when this crop follows rice in a rotation.

Other Highlights

- Seeds of parents, populations, and breeding lines were supplied to 49 breeders in 20 countries. Eight advanced lines were included in the All India Coordinated Trials in 1978–79.
- Mid-tall and compact breeding lines were derived for further testing. Using mid-tall and compact plants, it is possible to grow more plants per hectare and to produce more pods per plant than with the traditional low-spreading bushy types.
- A basic method for accelerated generation turnover was developed. Using off-season nurseries and environmental modification, we can now grow four generations per year in order to obtain quicker experimental results.
- Multilocational testing of early-generation breeding populations was initiated; this will better enable breeders to select suitable material for their local environments.
- Partial male sterility was detected; this raises the hope that male steriles essential for use in hybrid seed production can be developed.

ICRISAT's off-season nursery in Kashmir. Because of cooler weather there, a second crop of chickpea is obtained each year from this nursery for the purpose of scientific experiments.



Pigeonpea

Pigeonpea is an important grain legume grown widely in India and, in a vegetable form, in parts of Africa and Central America. It has high protein content (about 20%) and is a staple food in parts of the SAT, often being combined with rice, sorghum, or other cereal crop for meals. Despite its dietary importance, yields are low (around 600 kg/ha) and the crop has been pushed onto marginally productive land by higher-yielding cash crops.

Pigeonpea is a perennial shrub with woody stems and branches. Traditional cultivars have a short-day photoperiod response—they will flower only as days become shorter; thus their use is highly seasonal. Pigeonpea grows well during the rainy season but performs best when flowering and podding occur after the rains cease.

Early-Maturing Pigeonpeas

Encouraged by our results with inbred lines derived from existing cultivars, we identified several new lines of pigeonpeas this past year. Ten early-maturing lines were submitted to the All India Coordinated Trials. Two

A good pigeonpea line ready for harvest at ICRISAT Center.

of these had comparatively high yields at Badnapur, Junagadh, Rahuri, and Varanasi, giving an indication of satisfactory adaptation of such inbred lines. Eight medium-maturity inbred lines (two resistant to sterility mosaic) were also accepted by the Indian program for testing.

Two international trials of vegetable-type lines (for green pea harvest) were conducted, one of 26 early-maturing lines and the other of seven medium-maturing experimental lines. Results received from six locations showed that some of our experimental lines were superior to the local checks, particularly in Puerto Rico and Kenya.

Developing Disease Resistance

The three major diseases of pigeonpea are wilt, sterility mosaic, and *Phytophthora* blight. Wilt causes plants to completely dry out because of infection through the roots: the water-conducting tissues (xylem) become infected and the plant dies. *Phytophthora* blight infection causes lesions mainly on stems, which results in drying and breaking of plants. Sterility mosaic produces yellow and green mottled leaves, and, as a result of the infection, plants produce few or no flowers and are thus partially or totally sterile.

A nursery for carrying out screening for combined resistance to these three diseases was developed, and during the year we screened 866 selections from parents with resistance to at least one of the diseases. Seed from 121 single plants that showed no disease was collected for further evaluation.

In the All India Coordinated Trials one of our entries was discovered to have a high degree of resistance to blight; this line will be further tested.

The existence of strains of blight *(Phytophthora drechsleri* f. sp. *cajani)* was demonstrated; this explains why resistant lines developed at ICRISAT Center were found susceptible at some other locations.

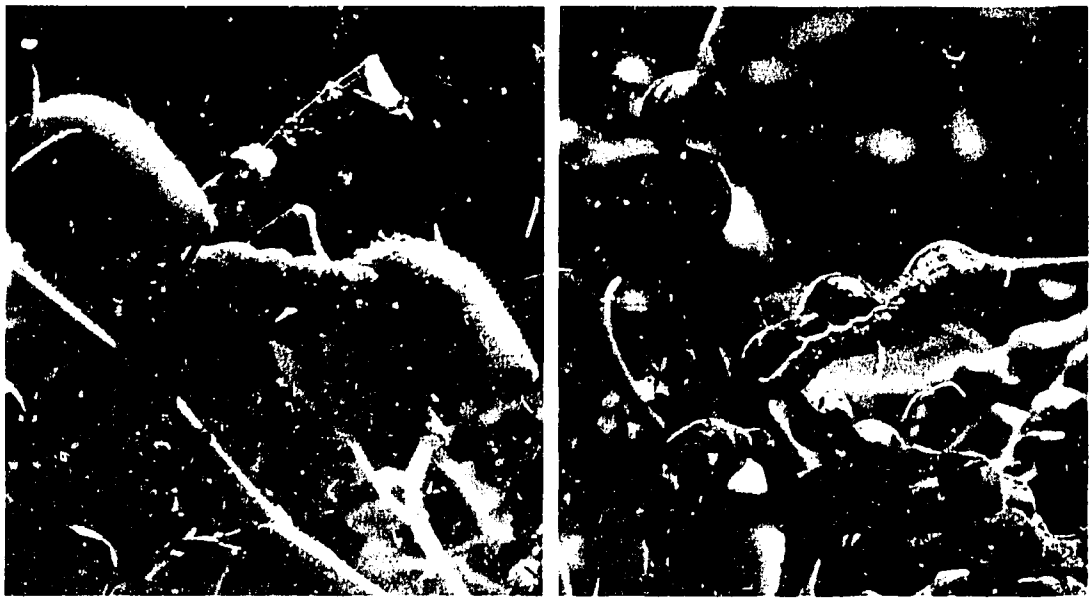
A large number of breeding materials and newer additions to the germplasm collection were screened in the field for resistance to sterility mosaic. After four generations of rigorous screening and selection, 29 out of 30 single-plant progenies of four germplasm accessions showed uniform resistance. Of 2092 selections from 1976 through 1978 screenings, nearly half were uniformly resistant. When the Pulse Program began its screening activities in 1976, there were no known sources of resistance to sterility mosaic.

Control of Pod Borer in Pigeonpea

Pod borer damage to pigeonpeas is a recurring annual problem more destructive than all the disease problems combined.

In experiments at ICRISAT Center we found some pigeonpea lines that have an ability to overcome damage from an early attack of pod borer. The first flush of flowers was completely damaged by the insect. But when the pod borer population reduced, a second flush of flowers was produced. Thus some cultivars gave reasonably good yields despite earlier damage. The ability to compensate for damage at early stages is greater in pigeonpeas than in chickpeas because the longer growing season of pigeonpeas gives more time for regrowth. This phenomenon is extremely important to the farmer who does not use pesticides and is in an area where the climate allows regrowth of the crop after destruction of the first flowering flush. This compensatory adjustment differs markedly among cultivars and is one of our more important selection criteria in the early and mid-maturing cultivars, which flower at the height of the pod borer season.

In our trials for selecting pigeonpea lines resistant to pest attack, it was confirmed



The pod borer (Heliothis armigera) *attacks both chickpeas (left) and pigeonpeas (right). It causes heavy yield losses and is a subject of major concern to ICRISAT scientists.*

that some lines are less susceptible to pod borer and podfly *(Melanagromyza obtusa)* —a regionally important pest.

Research in Australia

A significant portion of northern Australia consists of semi-arid tropics. Because the requirements of this area for mechanized farming could not be met at ICRISAT Center's research farm, cooperative research with the University of Queensland, Australia, was formalized in 1977. The primary objective has been the development of short-season pigeonpea genotypes and production systems suitable for mechanical harvesting in extensive dryland agriculture.

Most pigeonpea plants have indeterminate growth patterns: their pods mature at various times. However, mechanical harvest requires a determinate growth pattern—pods must all mature at the same time—and plant height must not be excessive. Royes, a medium-size cultivar with determinate growth, has been released in Australia, and commercial production is expected in 1979–80. The adaptation of this cultivar is limited by the incidence of frost, and earlier-maturing Royes-type breeding lines have been developed and introduced in Australia. They will be evaluated regionally in 1979–80.

These Royes-type lines are photoperiod-sensitive and thus must be planted before the shortest day of the year in order to flower. Development of short-season photoperiod-insensitive lines—which can be grown in any season—would be a significant accomplishment, as this would permit four crops a year in some areas. Our joint agronomic and breeding studies of such material has made good progress in 1979.

We now know that this material is capable of high seed yields, with some lines producing up to 4500 kg/ha in three pickings from the plant crop in experimental plots. We have selected from the most promising lines

those that appear to be synchronous in flowering and podding. These lines will be evaluated in regional trials in Australia and have been supplied to a number of cooperators internationally.

Other Highlights

- The feasibility of hybrid seed production was demonstrated on a field scale by the use of genetic male sterility to eliminate laborious hand pollination. This is generating considerable interest and is being further investigated.
- We obtained a 27% increase in yield by inoculating pigeonpea seeds with the nodule-forming bacterium *Rhizobium*. This occurred even though there were many rhizobia already present in the soil.
- We found that allantoin is the form in which nitrogen is transported from the roots to the other parts of the plant and are now working to establish the quantitative relationship between the amount of allantoin in stem tissue and the amount of nitrogen fixed in the root nodules. This would permit nondestructive assays of the nitrogen-fixing activity of plants in the field and of nodules too deep for excavation.

A wilt-resistant line of pigeonpea stands in contrast to a wilt-susceptible line (dried plants) at ICRISAT Center.

Review team evaluating ICRISAT research witnesses emasculation technique used to assure cross pollination in groundnut field.

Groundnut

Groundnut production in the semi-arid tropics is the largest of any legume crop: it equals the combined total for dry beans and chickpeas, the next two in importance. With 25% protein and 50% oil, groundnut is an important food crop in the SAT and, as one of the world's major sources of edible oils, an important cash crop as well. It is the only ICRISAT crop that enters world trade to any extent.

Although two-thirds of the world's groundnut is produced in the SAT, diseases, pests, and unreliable rainfall patterns impose severe limitations on production, which averages around 800 kg/ha compared with 3000 kg/ha or more in developed countries. However, a wide range of wild species survive in northern South America, with re-

Hand weeding groundnut at ICRISAT Center.

sistances to a host of diseases, pests, and other problems that plague the cultivated groundnut *(Arachis hypogaea)*. These are being assembled by our Genetic Resources Unit, as part of the world germplasm collection at ICRISAT Center.

Cytogenetics

Because the cost of inputs necessary to control the many problems of groundnut would be prohibitive for the small farmer, incorporation of genetic resistances to pests and diseases is most important in this crop. Therefore, the Groundnut Program utilizes wild species more than other ICRISAT crop improvement programs, and has a cytogenetics subprogram to cross useful wild species with the cultivated species, *A. hypogaea*.

Because *A. hypogaea* has more chromosomes than most wild species, several of the techniques used to cross these species rely on a chemical, colchicine, that can double the chromosome number.

This year the cytogenetics subprogram has succeeded in backcrossing to a range of cultivars several early-maturing, disease-resistant progenies derived from wild species. This makes new sources of desirable traits available to conventional breeding programs.

Groundnut leaves infected by rust, a major cause of yield loss throughout the SAT. ICRISAT scientists are making progress toward control of the disease.

Rust

One very important desirable trait now available from the cytogenetics work on wild species of groundnuts is resistance to rust, a fungal disease that forms orange-yellow pustules on the undersides of leaves, which eventually become chlorotic and die. Rust occurs in all the groundnut-growing areas of the SAT, causing significant damage (up to 40% yield loss at ICRISAT), and control of this disease could have a major impact on world production.

Good sources of resistance to rust also exist in cultivated groundnuts. ICRISAT's breeding subprogram crossed high-yielding and adapted Indian and American cultivars with four sources of rust resistance, and selections were advanced through several generations in various combinations with other genetic material. The cultivars produced from these efforts give promise that damage by this disease can be controlled in the very near future. A few of the rust-resistant cultivars also appear to have some tolerance to the leaf spot fungi as well. Rust-resistant parents and hybrids from ICRISAT have been supplied to scientists in China, Thailand, Senegal, and India.

Pathology studies on the nature of rust indicate that it is not carried from season to season on pods or seeds, and there is little danger of rust being spread by seed samples, especially if seed is stored at normal temperature for 2 months before distribution.

An infector row (center) of rust-susceptible groundnut is used to introduce infection among experimental cultivars. Spray irrigation creates wet conditions for optimum spread of the disease.

Viruses

Several of the diseases that cause severe groundnut crop losses in the SAT and worldwide are due to viruses, and ICRISAT has made progress on basic and applied aspects of the more important of these.

Bud Necrosis Disease

Tomato spotted wilt virus (TSWV) causes bud necrosis disease, which can result in up to 80% loss of yield in some localities. Extensive ICRISAT surveys have shown that bud necrosis disease is widespread in India and that 27 plant species, including nine common weeds of groundnut crops are hosts of TSWV. There is no evidence of TSWV being seedborne.

ICRISAT scientists have demonstrated that the thrips *Frankiniella schultzei* Trybom is an efficient carrier of TSWV on groundnut. Using thrips *F. schultzei*, we have successfully transmitted TSWV from groundnut to green gram, black gram, and tomato, and back to groundnut. *F. schultzei*, which is apparently primarily a flower feeder, occurs on 29 weed and cultivated plants, many of them the hosts of TSWV.

For the last two seasons in entomological screening, the cultivar Robut 33-1 was found to be much less susceptible to bud necrosis disease than the standard cultivar TMV-2, though the leaf damage due to *F. schultzei* injury was very severe. Results of field trials with and without insecticides indicate that the use of Robut 33–1 can substantially reduce bud necrosis disease.

Trials with the cultivar TMV-2 showed that actual numbers of bud-necrosis-

Leaf spot, a fungal disease, kills the leaves and causes serious yield losses of groundnut.

diseased plants on a unit area basis were highest in close-spaced crops. However, close spacing still gave the highest yield.

Yellow Spot Disease

This disease, characterized by the appearance of large yellow spots on groundnut leaves, was observed in several areas of India in 1978–79; in some crops, 80% of the plants were affected. ICRISAT scientists have growing evidence suggesting that this disease is also caused by a strain of TSWV. Electron microscope studies are being carried out to confirm identity. The virus was transmitted by the thrips *Scirtothrips dorsalis*, but not by *F. schultzei* or *Caliothrips indicus*.

Groundnut plants with yellowing leaves do not have nodules on roots and thus can't fix nitrogen biologically, as can the healthy nodulated plants with green leaves.

Peanut Clump Virus (PCV)

We have learned through electron microscopy that the virus particles are straight rods. The disease is soilborne and can cause severe damage to plants; even late infection reduces plant yields by up to 60%. PCV can readily be transmitted by growing seedlings in soil taken from around infected plants. The fungus *Olpidium brassicae*—known to transmit some viruses—and some species of nematodes that may act as virus carriers have been found associated with roots of clump-affected plants.

Nitrogen Fixation

This year at ICRISAT Center trials were run on two red soils using three groundnut cultivars and three *Rhizobium* cultures. The effect on pod yield was insignificant in the rainy season; however, when the experiment was repeated during the postrainy season, the cultivar Robut 33–1 and the North Carolina strain NC 92 gave a significant yield increase, from 3500 to 4500 kg/ha pod weight.

An important development at ICRISAT Center was the occurrence in an F_2 rust-screening nursery of nonnodulating plants, easily recognized by their yellow foliage. All the parents nodulated normally. Studies clearly indicate that ability to nodulate is inherited and thus might be increased by genetic manipulation. The genetic control of nodulation will be studied in future generations of groundnuts.

These nonnodulating plants can also be used as a valuable tool in studies of nitrogen fixation by groundnut because nodulating plants take up both atmospheric and soil nitrogen, whereas nonnodulating plants

take up only soil nitrogen. In no other legume crop except soybean are there non-nodulating plants that can be used in this way. The use of these enables precise study of the amount of atmospheric nitrogen taken up by various groundnut lines.

Other Highlights

- Fifty-four bulk selections that combine earliness with high yield potential were identified and will be used for breeding.

- Twenty-three cultivars selected as good parents for high yield and for yield-contributing factors were incorporated in the hybridization program with drought-, insect-, and multiple-disease-resistant material.

- Cultivars reported to possess dry seed resistance to invasion by the fungus *Aspergillus flavus* were screened. Resistance has been confirmed for one of them, and some germplasm lines have shown resistance in preliminary tests. *A. flavus* produces aflatoxin, the most powerful cancer-producing chemical known. It infects groundnut and other crops harvested or stored in damp conditions.

- We assessed the seed dormancy level of 151 cultivars in both the rainy and postrainy seasons; a wide range of dormancy was found only in the cultivars of subspecies *hypogaea*.

- The relationship between seasonal flowering patterns and production efficiency of mature pods was analyzed in 16 cultivars in the rainy and postrainy seasons. Drought at flowering was a major cause of reduced yields, and the cultivars that gave the best yields were those in which flower production was least affected by drought.

Roots of a well-nodulated groundnut plant. Nodules are formed by soil bacteria, which enable the plant to take up atmospheric nitrogen.

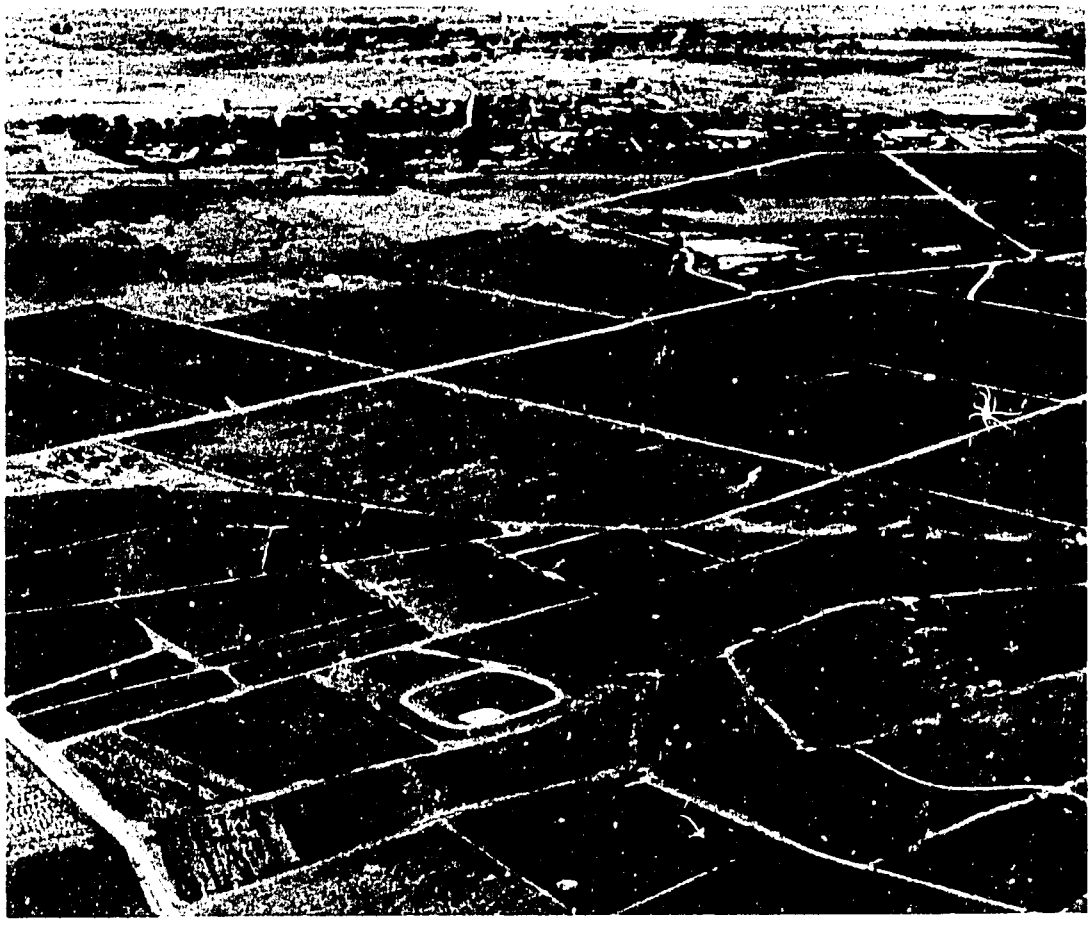
Farming Systems

When ICRISAT was founded in 1972 the first program to become operational was the Farming Systems Research Program (FSRP). Experiments were planted even before the formal commissioning of the Institute. In the years since then, ICRISAT has developed and refined a "whole-systems" approach to farming problems in the SAT, established a viable research program at ICRISAT Center, initiated collaborative research activities with host country scientists, and started on-farm research to develop more effective means for transferring technology to farmers of the SAT.

The Whole-Systems Approach

Farming systems research involves the study of the many factors that the SAT farmer has to deal with, ranging from how he grows his crops to how he copes with the socioeconomic constraints of his environment. Re-

Village farmer uses his bullocks and equipment from ICRISAT for interrow cultivation of groundnut crop on broadbeds and furrows in on-farm experiment in SAT India.



ICRISAT Center research farm. Most farming systems research is conducted in the watersheds in foreground. Precision fields in background are for crop improvement experiments.

search at ICRISAT Center includes studies within disciplines ("component research") as well as multidisciplinary approaches by teams of scientists in examining the integrated effect of various factors on crop production. This combination aims at development of packages of practices for particular agricultural situations. The most promising of these involve improvements in crop varieties and crop combinations, land and water management, farm equipment, and fertilizer use. After the development and thorough testing of these practices within the research station, their feasibility for the SAT farmer is evaluated in collaborative and on-farm research.

Double Cropping the Deep Vertisols

ICRISAT research has demonstrated that two crops can be grown on the same piece of land now producing only one crop in much of India. Traditionally, deep Vertisols

(black soils with high capacity to store moisture) in areas of assured rainfall are allowed to lie fallow during the monsoon or rainy season so that they will store up water for a crop to be grown during the postrainy season. The rainy-season fallow system results in serious runoff and erosion and inefficient use of the total available water. It is estimated that 20% of the net sown area in SAT India produces only a postrainy-season crop. In deep black soils alone, 15 to 20 million hectares are left fallow during the rainy season, but if results at ICRISAT Center can be duplicated elsewhere, approximately half of this area could be cropped using our new technology. Small farmers especially would benefit since more of them leave their land fallow during the rainy season than do large farmers.

ICRISAT farming systems research has demonstrated that, at ICRISAT Center, both a rainy-season crop and a postrainy-season crop can be grown on the same piece of land. This double cropping reduces runoff and erosion during the rainy season and makes better use of water.

The new technology involves the following combination of factors:

- The prediction of areas in which rainfall is sufficient to assure reliable double cropping.
- Shaping the land into graded broadbeds and furrows to facilitate cultivation and surface drainage.
- Preparing seedbeds during the dry season with improved bullock-drawn equipment.
- Sowing dry ahead of the rains before the soil becomes too wet and sticky to cultivate.
- Using improved varieties and combinations of crops with greater yield potentials than traditional crops.
- Applying improved fertilizers to amend nutrient deficiencies, especially those of nitrogen and phosphorous.

Having established the benefits and profitability of this system within the research station, ICRISAT is now preparing to test this technology in deep black-soil areas of India with assured rainfall.

Collaborative Research

To test the off-site performance of new methodologies of land and water management and crop production practices, we are conducting cooperative studies at several locations in India as a part of the ICAR-ICRISAT Collaborative Research Program. The scientists involved are from the All India Coordinated Research Project for Dryland Agriculture, the Central Soil and Water Conservation Research and Training Institute, the state agricultural universities, and the ICRISAT Farming Systems Research Program.

Initial results from our collaborative research project covering 12 centers confirm that the improved technology utilizing the 150-cm graded broadbed-and-furrow system developed at ICRISAT was most effective in increasing crop yields on the heavier soils and under medium to high rainfall conditions. Compared to flat cultivation, the use of ICRISAT-type graded broadbeds increased the yields of pigeonpea at Indore, pearl millet at Jodhpur, and maize and finger millet at Ranchi.

On-Farm Research

In three villages of SAT India where ICRISAT economists have been conducting stud-

Program leader explains recorder for measuring water runoff to scientists visiting ICRISAT Farming Systems Program.

ies since 1975, our scientists are now evaluating new technologies on farmers' fields. These experiments are being conducted jointly with the Indian Council of Agricultural Research and three agricultural universities in widely separated and different agroclimatic areas. They were started on a limited scale in 1978 and will continue through the 1980–81 crop year, after which the farmers will decide whether to continue to use the technology on their own. From 5 to 15 small farmers are involved in each of the three separate groups.

The objectives of on-farm research are: (1) to adapt, test, and measure the performance of the newly developed farming systems technology on farmers' fields, (2) to find ways for farmers to participate in the technology development process, and (3) to examine the feasibility of group action for adoption of watershed-based systems of resource development and management.

A 12-hectare watershed was developed in the red soils (Alfisols) of Aurepalle village during the dry season of 1978 when draft animals were customarily idle and laborers unemployed. The farmers were continuously involved in planning the work, and they also participated in the development activities. These consisted of the removal of stones and brush, a thorough cultivation, land smoothing, drainageway construction, and the layout and establishment of the semi-permanent broadbeds. An old shallow

well was restored and is being used to supply supplemental irrigation on a limited adjacent area. The development costs totaled about 450 Rupees (U.S. $56) per hectare; almost half of these costs were borne directly by the farmers. The watershed was planted to sorghum, castor, and a millet/pigeonpea intercrop early in the 1979 rainy season. Despite a mid-season drought, the crops performed much better than those grown by traditional methods.

Similar projects were initiated with six farmers on an 11-hectare medium black-soil watershed near Kanzara village and with eight farmers on a 14-hectare deep black-soil watershed near Shirapur.

Benefits of Intercropping

Many of the small farmers of the SAT attempt to gain the maximum from their small plots of land by intercropping or mixed cropping—growing two or more crops interspersed on the same piece of land. ICRISAT Farming Systems research therefore focuses much attention on methods to increase yield and improve stability through intercropping. Studies conducted this year show intercropping can be not only profitable but more dependable than sole cropping.

Sorghum/pigeonpea is an extremely important intercropping combination in India. The farmer's objective with this combination is usually to produce a "full" yield of sorghum (i.e., as much as from a sole crop) and some "additional" yield of pigeonpea. Previous ICRISAT experiments have shown that in any given season sorghum/pigeonpea intercropping can give appreciably higher yields than sole cropping. Studies were conducted this year to determine whether this combination also gives more stable yields year after year.

Data from ICRISAT sorghum/pigeonpea experiments and those reported from a wide cross section of India during the period 1972–78 were used. In all, 94 experiments ranging over different soil types and locations in India were considered. Where possible, information was obtained on sowing and harvesting dates, fertilizer levels, soil moisture characteristics, weekly rainfall, and evaporation. In the environments covered by this study, sole crop yields of sorghum and pigeonpea ranged from 310 to 6200 kg/ha and 270 to 2840 kg/ha, respectively; and the annual rainfall varied from 410 to 1160 mm.

Several approaches to measuring yield stability were followed, including an estimation of the probability of crop failure as measured by monetary returns falling below a given "disaster" level of income. Though all approaches showed some merit, estimating the probability of crop failure appeared to be the best and most reliable to reflect the farmer's attitude to stability. This approach revealed that sorghum/pigeonpea intercropping fails less often than either sole cropping or a "shared-sole" system in which a farmer grows some of each sole crop on different plots of land. Taking as an example a disaster level of 1000 Rupees (U.S. $125) per hectare, sole pigeonpea fails 1 year in 5, sole sorghum 1 year in 8, shared sole 1 year in 13, but sorghum/pigeonpea intercropping fails only 1 year in 36.

In sum, intercropping did indeed show much improved stability over sole crop systems. Thus the farmer gains not only in terms of higher yield but also in terms of greater stability of yield.

Rainfall Characteristics of Niger

Practical crop planning for the seasonally dry semi-arid regions of Africa needs a thorough understanding of the variability in the

Sorghum/pigeonpea is an important intercropping combination in the Indian SAT.

amount and occurrence of rainfall. Such studies are helpful in defining risk levels in arable agriculture, so that emphasis can be shifted to areas with reasonable or acceptable risk situations. In view of this, ICRISAT conducted a detailed study of rainfall characteristics of Niger in 1979 similar to that done earlier by our agroclimatologists in SAT areas of India. Rainfall studies in other countries in Africa, and other areas of the SAT, will follow.

Other Highlights

- On the raised broadbed-and-furrow system on red soils, 15% higher crop yields were obtained by increasing the amount of primary tillage.

- Emergence of seedlings on red soils at the beginning of the rainy season was improved by use of a solid planter press-wheel to compact the seedbed in the vicinity of the seed.

- Good potential was found for genotype improvement in millet/groundnut intercropping. Techniques are being developed for early-stage screening of millet genotypes with a standard groundnut, and groundnut genotypes

with a standard millet, to reduce the very large numbers of treatments that would have to be handled in "simultaneous" screening of all possible combinations.

- The effect of adding a cover crop to smother weeds was examined. The net return from a main crop of sorghum or pigeonpea intercropped with a smother-crop of cowpea or mungbean between the rows, and with one hand-weeding, was substantially higher than with two hand-weedings without the cover crop.

- An improved fertilizer distributor was developed. This uses a screw conveyor for improving the uniformity of fertilizer application rates.

A village bullock cart modified by ICRISAT engineers to utilize the tool bar and implements needed for field operations in new farming systems technology.

Economics Program

The primary goal of the Economics Program at ICRISAT is the identification of socioeconomic and other constraints to agricultural development in the SAT and the evaluation of alternative means of alleviating these constraints via technological and institutional changes. Research in the program is broadly divided into the fields of production and marketing and directly or indirectly supports ICRISAT's work in crop improvement and farming systems. One major function is to provide data that will help evaluate the agricultural technology being developed at ICRISAT, to ensure that it is relevant to actual conditions facing SAT farmers and that the potential for payoff is high.

Our Economics Program conducted a variety of studies in the past year designed to increase understanding and to help solve problems in production and marketing economics and the social organization of SAT

Farmers preparing to participate in a groundnut auction at a regulated market in SAT India; studies of such markets are an important part of the ICRISAT Economics Program.

agricultural production. We also started economics studies in Africa similar to those conducted in villages of India since 1975.

Agricultural Development in the Indian SAT

To evaluate major experiences of agricultural development in the Indian SAT, we carried out a detailed comparative study of the region. A total of 190 Indian districts are in areas having an annual rainfall range between 500 and 1500 mm. These districts comprise over three-quarters of the area producing ICRISAT mandate crops in India. Irrigation in the Indian SAT is relatively uncommon. So far, in areas where irrigation has expanded, cropping patterns have changed in favor of rice, wheat, and sugarcane.

In India, farmers have been slow to adopt high-yielding varieties (HYVs) of pearl millet and sorghum, compared with the progress made by HYVs of wheat and rice. HYVs of pearl millet spread rapidly for a few years after their initial introduction, until struck by downy mildew disease in many areas. Statistics indicate that pearl millet HYVs have continued to be successful where the crop is grown with good soil moisture or irrigation or where the varieties in question are relatively well adapted to local conditions. HYVs of sorghum seem to have been less successful due to several factors including harsh crop environments, suscep-

ICRISAT Economics Program scientist discusses with Indian farmers plans for on-farm experiments on development of watersheds in their village.

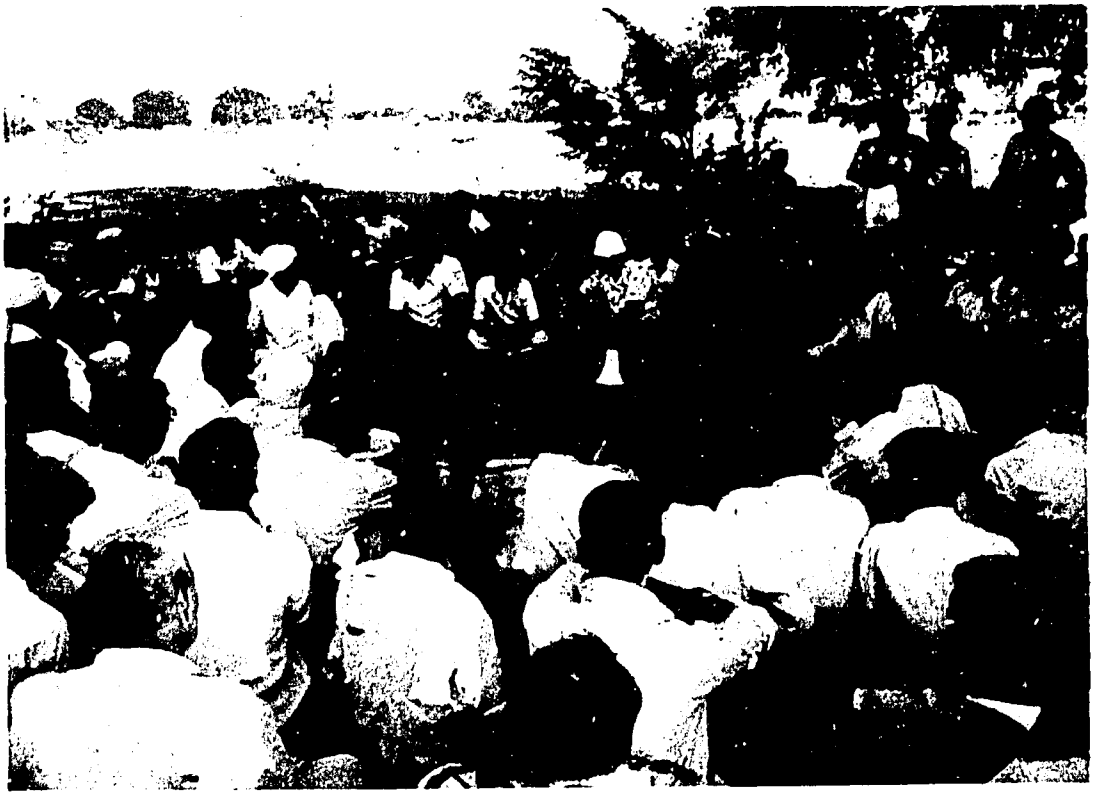
tibility to diseases and pests, and difficulties in meeting consumer requirements for grain quality or fodder. These preliminary conclusions regarding adoption of HYVs of both pearl millet and sorghum in India need to be evaluated against detailed and extensive farm-level data.

It seems that SAT Indian farmers are aware of the potential of fertilizers and that their actual use of fertilizers is influenced by the anticipated level and certainty of returns. There would be good scope for improvement in production of the ICRISAT mandate crops in India if more, better-adapted HYVs were available, if market demand increased and thus led to higher profits to farmers from these crops, and if measures to reduce risk were devised—including measures to conserve rainfall moisture and to improve its use.

Market Channels of ICRISAT Crops in India

Our estimates of market arrivals in 29 selected markets sampled in SAT India indicated that in the mid-1970s only 22% of sorghum was marketed and 78% was retained on farms or in villages. About 26% of pearl millet was marketed. Higher percentages of the grain legumes were marketed:

Participants at international socioeconomics workshop sponsored by ICRISAT meet with farmers in one of the study villages of SAT India where on-farm experiments are being conducted.



35% of pigeonpea, 45% of chickpea, and 80% of groundnut. Interregional trade in sorghum and pearl millet is concentrated within the SAT areas of India where these crops are used as staple food. The major producing areas for sorghum (Maharashtra State) and pearl millet (Gujarat State) are also the major importing regions for these crops. The pulses flow into other non-SAT areas.

In all the markets studied, large farmers participated more than small farmers. Generally, small farmers seemed to produce food for home consumption. When they did sell part of their crops, they usually used only nearby markets, possibly because of the small quantities of produce they had for sale and their transportation problems. We need to study access of various categories of farmers to markets in order to determine to what degree availability of markets affects farmers' incentives to produce. Means to increase small farmer participation in markets need particular attention.

Economic Assessment of Prospective Technologies

During the past year an economic assessment was made of the improved soil, water, and crop management technologies for the SAT, analyzing data from agronomic experiments carried out at ICRISAT from 1975 through 1978. The following points emerged:

- A complete, improved technology package generated maximum profits per hectare in small plot experiments at ICRISAT Center. The package, which was tested on both black soils and red soils, utilized improved seed varieties, fertilization, plant protection, and soil management; and used an improved, bullock-drawn wheeled tool carrier for all activities where it could be used.

- The maximum profits from the improved technology package were achieved well within risk levels acceptable to Indian SAT farmers.

- On the deep black soils at ICRISAT Center the broadbed-and-furrow system of soil management, with improved crop management, was highly profitable in the large-scale experiments.

- On the red soils at ICRISAT Center profits from improved soil and crop management were also attractive

A market in SAT Africa. ICRISAT economists will study markets such as this as part of research now beginning in Africa.

in the small-scale experiments, although 60% less than on the black soils.

- A profit was not obtained from improved soil and crop management on the medium-deep black soils in large-scale trials at ICRISAT Center.

- Traditional cultivation and crop management were more profitable than improved methods on the large-scale red soil experiments.

Economics of Improved Tool Carrier

A study of the economics of a bullock-drawn wheeled tool carrier showed that increases in utilization can produce large reductions in rental rates for the machine. This suggests that widespread adoption of this equipment may depend upon such factors as size of the areas where it is used, yield increases from its use, and the extent to which it can be used for other purposes such as hauling.

Field Studies of Watershed Development and Group Action

Experiments were initiated during 1978-79 to test in farmers' fields systems of watershed development evolved at ICRISAT Center and the reaction of the farmers to them. The experiments are being conducted by ICRISAT's Farming Systems and Economics Programs in cooperation with farmers from three villages and with member institutions of the Indian Council of Agricultural Research. (See the Farming Systems section of this report for further details.)

The watershed areas being studied involve groups of from 5 to 15 farmers. They are located in each of three central peninsular Indian agroclimatic and soil subregions under study since 1975 in ICRISAT's Village-Level Studies (VLS). Farmers are protected against financial loss from failure of the experiment for its 3-year duration, and they provide substantial amounts of the labor and bullock power used.

The farmers' reactions to the technologies and to the types of group action involved are being monitored. They will also be observed when the present management assistance and financial aid end at the end of the 1980-81 crop season, to gauge their willingness to adopt the new methods at their own risk. Concurrent, supplementary studies on the social organization and the economics of watershed-based agricultural development are being undertaken.

Labor Availability and Allocation

A detailed study of farm labor availability and allocation was carried out using data from 240 sample households in central peninsular India. Results included the following:

- Both male and female labor participation in the central Indian SAT are key factors of production and show rather different characteristics. Males account for relatively more family labor and females account for a relatively greater portion of the hired labor used.

- Females as a group receive the lowest daily wages and females from the poorest socioeconomic group are the most disadvantaged in terms of employment opportunities.

- Wide seasonal variability in wages paid suggests there is good scope for designing technology that will use more labor during periods when wages are low. Besides benefiting the employer, this would also increase employment.

African housewife carries grain home from the field.

International Cooperation

The year 1979 was one of consolidation of the research programs at the sites selected for ICRISAT's work in the semi-arid countries outside of Asia. Major emphasis continued on sorghum and millet improvement in the West African region, and considerable progress was also made in the Sudan, Tanzania, and Mexico. In particular, the chickpea breeding program in Syria underwent considerable development.

ICRISAT scientists posted to SAT countries are closely associated with the national programs; this year they increased their international and regional role in effecting rapid transfer of germplasm and breeding material, including pest- and stress-resistant material for accelerating local research in breeding. Efforts were intensified to collect landraces of ICRISAT's mandate crops as a safeguard against possible loss of such genetic stocks because of the popularity of new cultivars introduced in several countries.

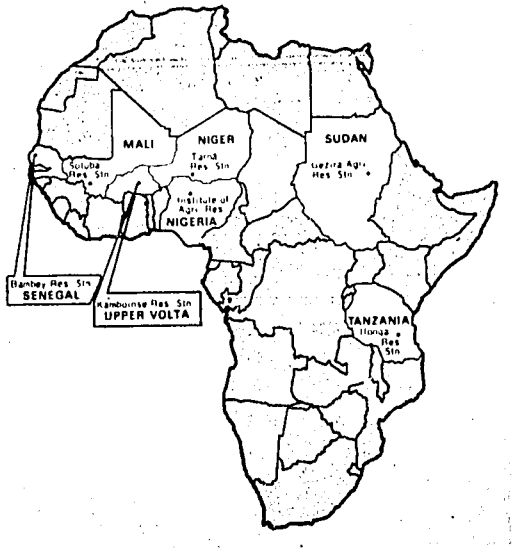
Africa

Scientists in the African program maintain close linkages with the research programs at headquarters in India and also with ICRISAT scientists in specially funded projects in other countries. All our African work takes place at national research centers of the countries concerned. In some instances, ICRISAT has assisted with the development of facilities, including buildings and land, at these centers. Significant expansion of the Upper Volta government station at Kamboinse was initiated this year. The station serves as a base for the largest ICRISAT multidisciplinary team in Africa and as a center for improvement of crops for the Sahelian area.

By the end of 1979 the ICRISAT staff in Africa numbered 19 and included the following:

- A project manager, posted at Dakar.
- Five sorghum breeders, two in Upper Volta, one in the Sudan, one in Mali (who is also responsible for millet breeding), and one in Tanzania.
- Five millet breeders, one each in Senegal (Bambey), Upper Volta (Kamboinse), Niger (Maradi), Nigeria (Samaru), and the Sudan (Wad Medani).

LOCATIONS OF ICRISAT SCIENTISTS IN AFRICA



- Two entomologists, one in Senegal and one in Upper Volta.
- Two pathologists, one in Nigeria and the other in Upper Volta.
- Three agronomists, two posted in Upper Volta and one in Mali.
- An economist posted in Upper Volta.

Sorghum Program

The aim of the program is to produce sorghum cultivars suitable for the highly varied situations of the SAT areas of West Africa. Such cultivars will have higher, more stable yield capability than the landrace cultivars presently grown, while retaining the desirable consumer preference characteristics for the different areas. Yields on farmers' fields currently average 600 to 900 kg/ha. A doubling of even the lower level would have a very significant effect on the living standards and nutritional status of some of the world's poorest peoples.

Major emphasis was given this year to breeding pure-line varieties that will mature in 150 days in deep soils, 120 days in medium-deep soils, and 105 days in shallow soils. Of 900 entries evaluated in a preliminary trial, more than 80 originating from ICRISAT Center, the Ford Foundation's

African farmer and ICRISAT scientist examine a head of E35-1, an improved ICRISAT sorghum line being grown in Upper Volta.

A bumper crop of sorghum harvested and stacked for drying in Botswana; light colored grains are used for food, brown grains for making beer.

ALAD program, and Texas A&M University were selected for further study. Considerable promise was shown by some introductions from overseas. One overseas cultivar, E35–1, was particularly promising in trials at research sites and will be introduced next year on fields of selected farmers. It was among three lines that gave considerable yield increases over traditionally grown cultivars of the districts concerned.

Useful results were obtained from a trial of advanced breeding material distributed to Senegal, Mali, Sudan, Upper Volta, and Niger. During the year a full-scale program on the parasitic sorghum weed *Striga* was started in Upper Volta. Another major objective of the program in Mali this year was to identify short-season sorghums with greatly increased yield over traditional cultivars grown in the 400- to 800-mm rainfall zone. Fifteen promising cultivars were selected for field test.

In Sudan, a large crossing program and work on hybrids was initiated. Selection of promising materials will begin in 1980.

Millet Program

The major emphasis of ICRISAT's work in West Africa is on pearl millet improvement, in view of this crop's position as the preferred cereal in the drier areas of the region. Traditionally, farmers' cultivars have good yield stability and grain quality. However, yields are low (400 to 700 kg/ha), in spite of the fact that the crop has exceptional

Technician gathers pearl millet germplasm for ICRISAT collection from backyard of an African farmer.

drought resistance and adaptability to poor environments. Most of the cultivars that are grown flower at the end of the rains, and residual soil moisture is often not sufficient for grain filling. We believe that yields can be improved and good grain quality maintained by breeding cultivars with a maturity that more nearly matches the length of the growing season and by improving ergot resistance.

Improved local populations are being utilized along with exotic materials from India and other millet-growing areas of Africa in ICRISAT's improvement program to breed for earliness, better plant architecture, and synchronous tillering. The Indian exotics generally have been found to be susceptible to disease, but they have otherwise favorable characteristics. More use will be made of millet in the West African germplasm collection, which has been used only to a limited extent in the past.

Farming Systems

Conditions on experiment stations, and in crop agronomy trials directed towards sole cropping, are very different from the situation existing in farmers' fields. Significant progress was made this year, both in Mali and Upper Volta, in the study of local farm systems at the village level, and plans were made for on-farm experimentation in the 1979 season. Experiments were also laid

A farmer in Africa with her sorghum crop stacked for drying.

down on research sites to study different systems of land management—forming it into ridges or mounds, or flat cultivation, etc.—to obtain maximum emergence and moisture infiltration and retention.

It is proposed to greatly expand the work on farming systems over the next few years, both on farmers' fields and on land resettlement schemes such as the valley management scheme in Upper Volta (AVV).

Asian Cooperative Programs

A major part of ICRISAT's cooperative research effort is focused on southern Asia, where nearly two-thirds of the population of the semi-arid tropics is concentrated. India, the base for ICRISAT's headquarters and much of its research, has 350 million people living in semi-arid tropical regions—56% of the total world SAT population. Other Asian countries have 7%. Most of these people are villagers and small farmers living and working at subsistence levels.

India

ICRISAT works closely with the Government of India, and with state governments in the Indian SAT, in carrying out its research. The Director General of the Indian Council of Agricultural Research, the Secretary of Agriculture of the Government

of India, and the Chief Secretary of the State of Andhra Pradesh where Hyderabad is located are members of the ICRISAT Governing Board. The Government provided the 1394-hectare site for ICRISAT Center and has helped the Institute to develop cooperative research substations at agricultural universities in four separate and distinct regions of the country. These substations provide a range of environments for work on disease resistance in sorghum, pearl millet, pigeonpea, and chickpea. The substations are at Bhavanisagar (11° N), Dharwar (16° N), Gwalior (26° N), and Hissar (29° N). Without them, ICRISAT could not fulfill its obligations to some of the African SAT regions, nor could it carry out breeding work on resistance to diseases and pests for which conditions at ICRISAT's Hyderabad location are not suitable.

Other Asian Countries

This year ICRISAT also continued to expand its cooperative research activities with the neighboring countries of Bangladesh, Pakistan, Nepal, and Sri Lanka. We provided technical assistance, training, and breeding materials to their scientists, as well as germplasm and international nurseries of crops of particular interest to them, and exchanged visits with them.

ICRISAT's cooperative work is extending

Harvesting chickpeas at Haryana Agricultural University experimental farm, Hissar, one of four such locations in India where ICRISAT operates substations in cooperation with the Government of India.

Young scientists from Thailand were among those who received training at ICRISAT during 1979.

to other Southeast Asian countries, particularly to Thailand, the Philippines, and Indonesia. Increasing interest has been shown by Thailand in sorghum and farming systems research, and the Thais have also carried out some exploratory trials with chickpea, pigeonpea, and groundnut. We feel that our cooperation with the Southeast Asian countries will grow as more technical manpower interested in ICRISAT programs becomes available in this region. The interest of these countries in ICRISAT technology is primarily directed toward exploring the possibility of growing crops, like sorghum, for the export market. Secondly, they are keenly interested in making use of relevant farming systems technology to exploit the potential of soil and water under rainfed agriculture or in dry periods.

Cooperation with Organizations

ICRISAT continues to extend and foster its links with scientific laboratories in the host country, India, and in various other nations in the developing and developed world. Strong ties have been made with universities in Australia, the UK, the USA, and Canada. Arrangements for collaborative research made in 1979 included staff deployment at ICRISAT for the growing season, in the

environmental physics program with Nottingham University, UK, and in the pigeonpea program with the University of Queensland. An excellent and useful cooperative program on genetic improvement of groundnut involves North Carolina State University, USA, the University of Reading, UK, and ICRISAT. There are continuing links with the University of Saskatchewan in Canada on drought stress; joint meetings were held to assess progress and future research.

ICRISAT has cooperative links with several research institutes in the form of joint projects, such as one for control of *Heliothis armigera* using virus, with the Boyce Thompson Institute in the USA; biology of shoot fly financed by IDRC, with the International Center of Insect Physiology and Ecology in Kenya; biology of *Chilo* stem borer and plant resistance chemicals, with the Center for Overseas Pest Research (UK); *Striga* stimulants, through a British ODA project, with the Weed Research Organisation and Sussex University (UK); nitrogen fixation and *Rhizobium*, with CSIRO Australia; plant chemicals and insect attractants, with the Max Planck Institute in Germany and many others. Such relationships are proving to be mutually very beneficial, and as more opportunities are identified they will be developed. Generally, financing of these projects is by donors interested in these particular research areas.

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J.C. Davies, Director for International Cooperation
C.Charreau, Project Leader West Africa (Dakar, Senegal)
B.F. Dittia, IAS, Principal Administrator
V. Balasubramanian, Executive Assistant to Director General
O.P. Shori, Fiscal Manager
S.K. Mukherjee, Personnel Manager (until April 1979)
B.K. Johri, Personnel Manager
R. Vaidyanathan, Purchase & Stores Manager
A. Banerji, Assistant Manager (Fiscal)
R. Seshadri, Assistant Manager (Purchase & Stores)
R.G. Rao, Manager (Records)
S.K. Dasgupta, Scientific Liaison Officer (Visitors Services)
A. Lakshminarayana, Junior Scientific Liaison Officer (Visitors Services)
S.B.C.M. Rao, Travel Officer
R. Narsing Reddy, Transport Officer
P.W. Curtis, Security Officer
N. Rajamani, Liaison Officer, New Delhi Office

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Sorghum

L.R. House, Principal Plant Breeder and Leader
L.K. Mughogho, Principal Plant Pathologist
J.M. Peacock, Principal Plant Physiologist
Gebisa Ejeta, Sorghum Breeder, Wad Medani, Sudan
J.A. Frowd, Cereal Pathologist, Ouagadougou, Upper Volta
S.Z. Mukuru, Sorghum Breeder, Kilosa, Tanzania
C.M. Pattanayak, Sorghum Breeder, Ouagadougou, Upper Volta
K.V. Ramaiah, *Striga* Physiologist, Ouagadougou, Upper Volta
J.F. Scheuring, Sorghum/Millet Breeder, Bamako, Mali
W.A. Stoop, Agronomist, Ouagadougou, Upper Volta
Vartan Guiragossian, Sorghum Breeder, Mexico
K.F. Nwanze, Cereal Entomologist, Ouagadougou, Upper Volta
Bholanath Varma, Plant Breeder
D.S. Murthy, Plant Breeder
B.L. Agrawal, Plant Breeder
B.V.S. Reddy, Plant Breeder
M.J. Vasudeva Rao, Plant Breeder
N. Seetharama, Plant Physiologist
R.K. Maiti, Plant Physiologist
K.N. Rao, Plant Pathologist
S.R.S. Dange, Plant Pathologist
K.V. Seshu Reddy, Entomologist
H.C. Sharma, Entomologist
S. Krishnan, Executive Assistant

Pearl Millet

D.J. Andrews, Principal Plant Breeder and Leader (on study leave)
R.J. Williams, Principal Plant Pathologist and Acting Leader
F.R. Bidinger, Principal Plant Physiologist
Aran Patanothai, Principal Plant Breeder
R.T. Gahukar, Cereal Entomologist, Bambey, Senegal
R.P. Jain, Millet Breeder, Wad Medani, Sudan
A. Lambert, Millet Breeder, Bambey, Senegal
P.K. Lawrence, Millet Breeder, Ouagadougou, Upper Volta
S.O. Okiror, Millet Breeder, Samaru, Nigeria
P.G. Serafini, Agronomist, Bamako, Mali
B.B. Singh, Millet Breeder, Maradi, Niger
N.V. Sundaram, Cereal Pathologist, Samaru, Nigeria
S.C. Gupta, Plant Breeder
K. Anand Kumar, Plant Breeder
B.S. Talukdar, Plant Breeder
K.N. Rai, Plant Breeder
S.B. Chavan, Plant Breeder
G. Alagarswamy, Plant Physiologist
S.D. Singh, Plant Pathologist
R.P. Thakur, Plant Pathologist
S.P. Wani, Microbiologist
R.V. Subba Rao, Microbiologist
V. Mahalakshmi, Plant Physiologist

Pulses

J.M. Green, Leader
Y.L. Nene, Principal Plant Pathologist
P. J. Dart, Principal Microbiologist
W. Reed, Principal Entomologist

K.B. Singh, Chickpea Breeder, Aleppo, Syria
D. Sharma, Senior Plant Breeder, Pigeonpea (on leave)
K.C. Jain, Plant Breeder, Pigeonpea
Onkar Singh, Plant Breeder, Chickpea (on leave)
C.L.L. Gowda, Plant Breeder, Chickpea
S.C. Sethi, Plant Breeder, Chickpea
Jagdish Kumar, Plant Breeder, Chickpea
K.B. Saxena, Plant Breeder, Pigeonpea (on leave)
L.J. Reddy, Plant Breeder, Pigeonpea
S.C. Gupta, Plant Breeder, Pigeonpea
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S.S. Lateef, Entomologist
S. Sithanantham, Entomologist
M.V. Reddy, Plant Pathologist
M.P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist
O.P. Rupela, Microbiologist
J.V.D.K. Kumar Rao, Microbiologist
Satish Rai, Plant Breeder, Pigeonpea
G.K. Bhatia, Plant Breeder, Pigeonpea
I. Madhusudhana Rao, Plant Physiologist

Groundnut

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J.P. Moss, Principal Cytogeneticist
K. Maeda, Visiting Scientist, Plant Physiology
Duncan McDonald, Principal Plant Pathologist
N. Iizuka, Plant Virologist
D.V.R. Reddy, Senior Plant Pathologist (Virology)
S.N. Nigam, Plant Breeder
A.M. Ghanekar, Plant Pathologist
P. Subrahmanyam, Plant Pathologist
V.K. Mehan, Plant Pathologist
P.T.C. Nambiar, Microbiologist
P.W. Amin, Entomologist
A.K. Singh, Cytogeneticist
D.C. Sastry, Cytogeneticist
S.L. Dwivedi, Plant Breeder

Farming Systems

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J.R. Burford, Principal Soil Chemist and Acting Leader
J. Kampen, Principal Agricultural Engineer, Soil and Water Management
M.B. Russell, Consultant (Soil Physics)
G.E. Thierstein, Principal Agricultural Engineer, Small Implements Development
S.M. Virmani, Principal Agroclimatologist
R.W. Willey, Principal Agronomist
M.C. Klaij, Assistant Agricultural Engineer
F.P. Huibers, Assistant Agricultural Engineer
J.Ph. van Staveren, Assistant Agronomist, Ouagadougou, Upper Volta
S.V.R. Shetty, Agronomist
Piara Singh, Soil Physicist
Sardar Singh, Soil Physicist
T.J. Rego, Soil Chemist
K.L. Sahrawat, Soil Chemist
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M. Natarajan, Agronomist
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D. Jha, Senior Visiting Economist
V.T. Raju, Economist
R.P. Singh, Economist
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Plant Quarantine

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T. Nagur, Training Officer

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