ICRISAT
Research Highlights
1984

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Cover: *Market scene in a Burkina Faso village. Sorghum, pearl millet, and groundnut are among the food grains being sold.*

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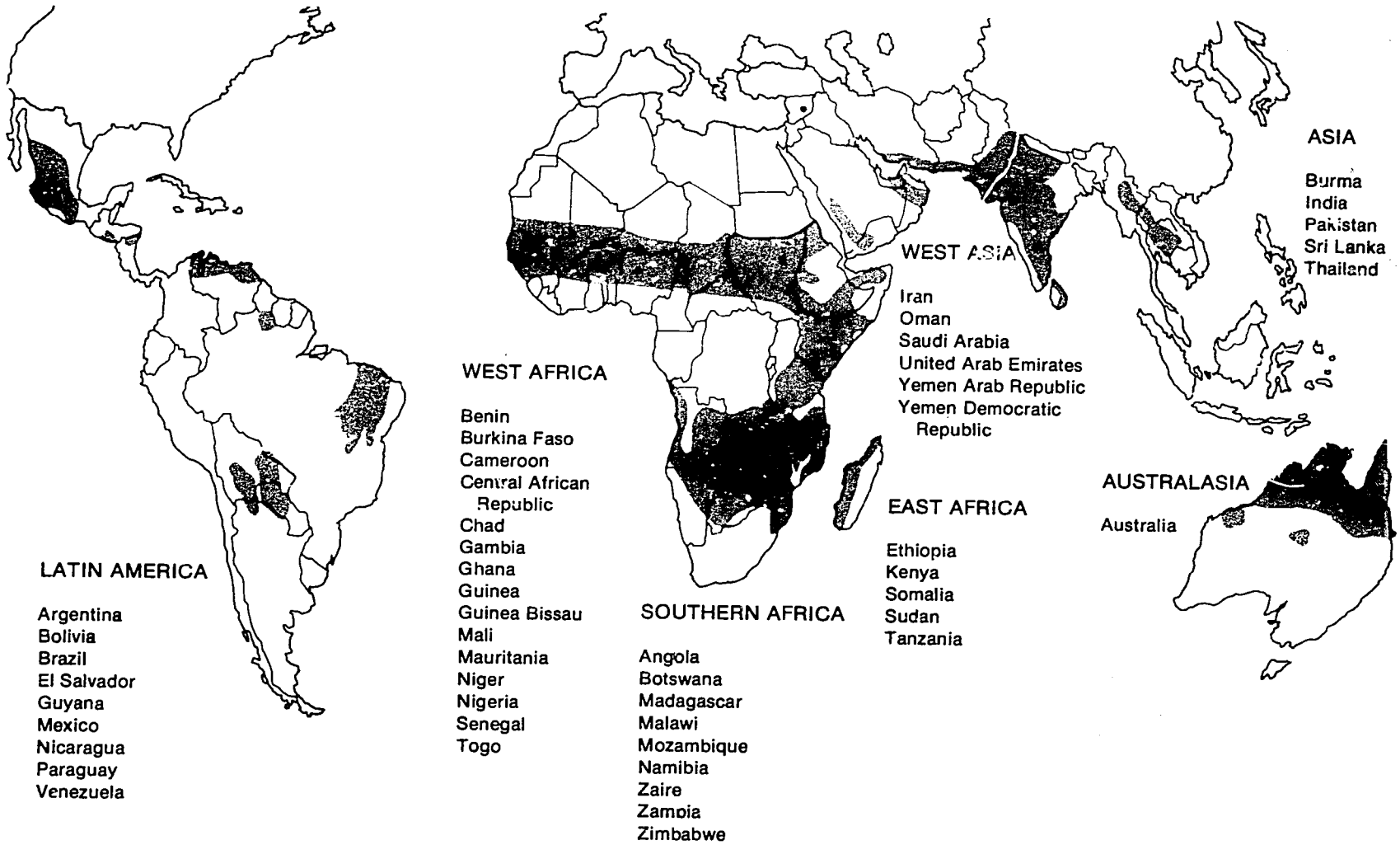


Semi-arid areas (in yellow) covered by ICRISAT's mandate. Green squares indicate location of ICRISAT Center in India and Sahelian Center in Niger; red dots indicate collaborative research stations with resident ICRISAT staff.

About ICRISAT

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 50 nations on five continents. They include much of South Asia, parts of Southeast Asia, West Asia, and Australia, two wide belts of Africa, areas of South America and Central America, and much of Mexico.

The SAT is a harsh region of limited, erratic rainfall and nutrient-poor soils. It is populated by more than 700 million people, most of whom live at subsistence levels and depend for their food on the limited production of small farms.

The crops researched by ICRISAT are sorghum and pearl millet—two of the major cereals in the SAT—and chickpea, pigeonpea, and groundnut, the most important food legumes of the region. Groundnut, rich in oil, is also an important cash crop for the SAT farmer. The four others are all primarily subsistence food crops; over half the total production of each—in some places nearly all of it—is consumed on the farms where it is grown.

ICRISAT's headquarters are at Patancheru, India, 26 km northwest of Hyderabad, but it also has scientific staff posted in nine countries of Africa, in Mexico, in Syria, and at six cooperative research stations of agricultural universities in India. Principal operations in Africa are in Burkina Faso, Kenya, Malawi, Mali, Niger, Nigeria, Senegal, Sudan, and Zimbabwe. The main base for ICRISAT's future work in Africa will be at the new Sahelian Center near Niamey, Niger. Other scientists are posted at experiment stations of the countries concerned.

Introduction

The recurrent drought in parts of Africa this year underscored the need for continued efforts to mitigate its effects, and to enable the small farmer to cope with the devastation that long-term drought brings.

While there can be no miraculous turnaround, ICRISAT made important progress in 1984 in evolving long-term solutions to the harsh environmental stresses under which crops grow in the semi-arid tropics, especially in the African Sahel.

A foothold in this battle is being established at the ICRISAT Sahelian Center at Sadoré, near Niamey, Niger. In a year of record low rainfall—the lowest in 78 years—careful agronomic management yielded good results there with millet and cowpea. Grain yields at the Sahelian Center averaged four to five times as much as on local farms.

ICRISAT sorghums, millets, and a chickpea cultivar were released to farmers in different parts of the world. Other lines of those crops—and pigeonpea and groundnut—did well in advanced national testing and moved a step nearer release. Released varieties are important, but an even greater impact can be expected from the many improved breeding lines already supplied by ICRISAT to national programs for adaptation and release by them.

Diseases and insect and weed pests are other major yield reducers of crops across the semi-arid tropics. Important progress was made by ICRISAT scientists this year, both in developing resistant lines and in identifying causal factors and relationships, work that could lead to the developing of several more resistant lines for each crop. While named sources of resistance are available for each major disease or pest, we are continuing to develop combined and multiple resistance to ensure stable yields across a range of environments.

We also continued work on establishing a broad genetic base for crop improvement, helping plants exploit air and soil nutrients to grow better and yield more food, and improving farming systems to help farmers exploit the available inputs to the maximum. The farming systems work included improving simple equipment for use by small farmers.

Progress on those and other aspects is outlined on the following pages, and can be read in fuller detail in the 1984 Annual Report.

Two external reviews conducted in 1984—on ICRISAT's research and training activities and on its management—confirmed that we are on the right track. The reviews suggested a gradual move toward more strategic

External Program Review panel visits a study village in Niger, where ICRISAT is conducting an experiment jointly with the International Fertilizer Development Center

research, more efforts to help strengthen national programs, including training, and the development of long-term research and management plans.

The Institute has accepted those major recommendations, and hopes to push forward more effectively toward improving the quality of life of many millions in the semi-arid tropics. The establishment of a research base at the ICRISAT Sahelian Center and the forming of a network of relationships in Africa should help us along.

The problem of drought and chronic food shortages in Africa has many dimensions. ICRISAT's main role is in research for the longer term. Short-term gains will be visible in the varieties or lines released, but much more needs to be done to strengthen the research base for tackling the problems that will emerge on a continuing basis.

We fully recognize this. Not only has our work on crop improvement paid due attention to strategic research, but our socioeconomic research also has been strengthened in recent years. In addition, ICRISAT's training activities have widened to include a larger number of disciplines and countries, so that national programs get stronger and more self-reliant.

The problems of crop production in Africa will continue for many years to come, but they are receiving our priority attention.

L.D. Swindale
Director General

Establishing a Research Base in the Sahel

In the Sahel of Africa, one of the most hostile environments for crop production, ICRISAT is establishing a foothold against drought and the advance of the desert. It will take a long time to overcome the devastating effects that drought has on farmers in the semi-arid tropics of the world, but research results in 1984 were encouraging.

The front line in this battle is at the ICRISAT Sahelian Center at Sadoré near Niamey, Niger, the headquarters for ICRISAT's research in West Africa. ICRISAT scientists are posted at nine other locations in eight African countries. Strong backup is provided from ICRISAT Center in India, where scientists have been working for years to understand the mechanisms of adaptation to drought (see page 17).

Thirteen principal scientists now make up the team based at the Sahelian Center. They include scientists from our sister institutes IITA and ILCA (working on cowpeas and livestock), IFDC (soil fertility), Texas A&M University (soils and agroforestry), and University of Wageningen (water management). Together with ICRISAT scientists, they mount an international effort to cope with the harsh environmental conditions of the Sahel.

Although farm development and field research have been under way for 3 years on the site at Sadoré, the Institute is only now ready to begin constructing laboratories and offices that eventually will complete this research facility. Funds donated by the Governments of Italy, Switzerland, and Nigeria are making it possible to begin.

Granaries near Maradi, Niger. Research efforts now under way will try to keep the grain pots adequately filled even in years of drought.

Above, an experimental millet field at ICRISAT Sahelian Center. Below, a drought-hit farmer's field in Bema, Mali.

Rainfall for 1984 at Niamey was the lowest in 78 years. It was only 250 mm, compared with a normal rainfall of 570 mm. But with careful agronomic management of the rains received in May and early June, the millet crop was established. Cowpea was sown with the early rains in July, and by the end of that month, crop growth was good.

In August and September, the crops were under severe drought, and the grain filling of millet was significantly affected. Lack of rain during August and September led to the millet crop lodging (falling over) at maturity.

The severe drought caused reductions in both crops. But the average yield at the Sahelian Center with millet cultivar CIVT was 800 kg per hectare, compared with average yields of about 200 kg under traditional farming in the region. Short-duration cowpea withstood the drought stress, and early harvests yielded up to 1000 kg per hectare, four to five times as much as local late-maturing varieties.

Intercropping millet and cowpea is one of the most important agricultural systems used by small farmers in the Sahelian zone. New varieties of cowpea are being fitted with millet into farming systems at the Sahelian Center by scientists from IITA. Cowpeas fulfill an important role in cropping systems. Their ability to nodulate with soil rhizobia and fix nitrogen from the air enables the subsistence farmer to produce more protein-rich food with minimal inputs.

In the sandy soils of the Sahel, plant establishment is beset by several problems, resulting from soil and climatic factors. Seedlings are blasted and buried by sand driven by strong easterly winds prior to rains. High soil temperatures and low moisture also affect emergence of seedlings. At the Sahelian Center, tillage methods prior to sowing have been improved to aid the crop to establish and grow.

In their third year of experiments there with millet, ICRISAT scientists confirmed that improved tillage and planting methods significantly increased initial establishment, seedling growth, and grain yield. Plowing and ridging increased the plant stand 50%; adding fertilizer produced cheaply from local rock phosphate increased grain yield 25%; a mulch of millet stalks (4 tonnes/ha) increased grain yield 16 to 32%.

In cooperation with U.S.AID's Semi-Arid Food Grains Research and Development project (SAFGRAD), ICRISAT's maize/millet intercrop package was tested on 15 farmers' fields in the Sikasso region of Mali; the intercrop yielded 45% more grain than the sole crops for the same area.

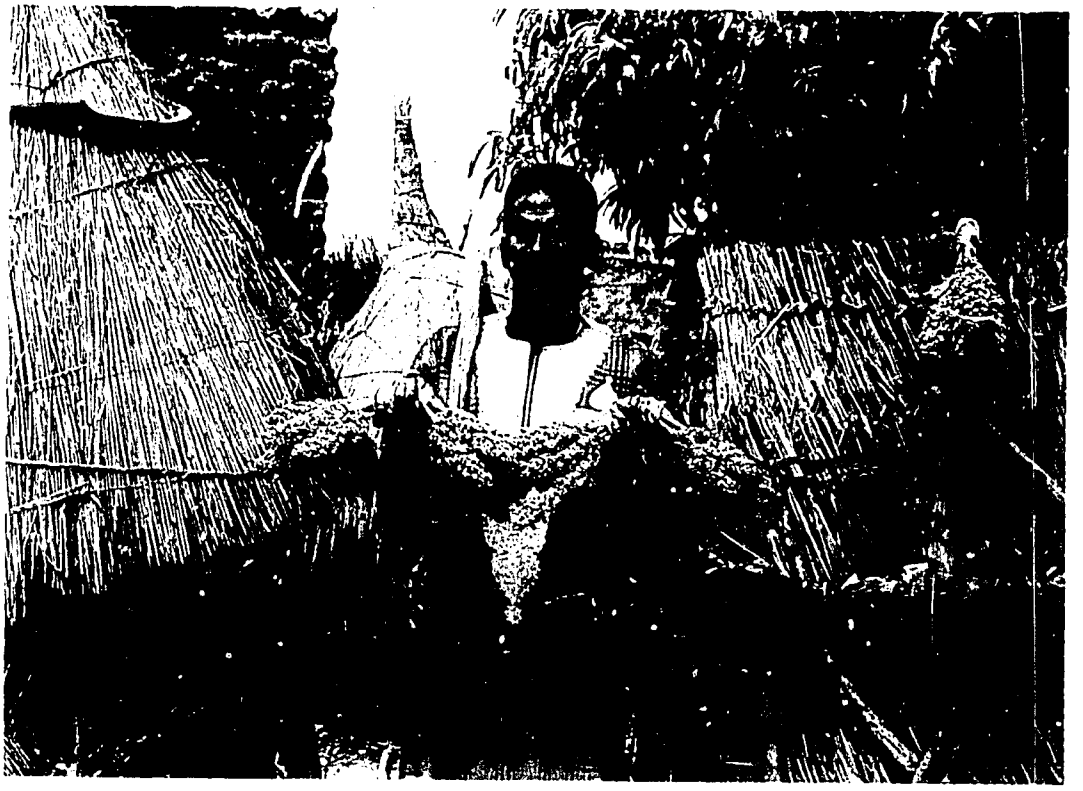
Three ICRISAT varieties, developed in cooperation with the Institut National de Recherches Agronomiques du Niger (INRAN) at the Tarna research station at Maradi, Niger, are being considered for release to farmers in that country in 1985, based on their performance in multilocational trials.

The Institut du Sahel has recommended two ICRISAT pearl millet varieties for farmers' field trials in millet-growing countries of the Sahel in 1985, based on 3 years of multilocational trials in the region, coordinated by that Institute.

In the same trials, five other millet varieties have given better and more stable yields than the local varieties. Preliminary evaluation of 92 pearl millet hybrids at Sadoré indicated that hybrids can potentially give higher yields than improved varieties, and the six most promising hybrids will be evaluated further.

Trials in Burkina Faso have identified promising materials for further testing and adaptation. Two pearl millet varieties with low susceptibility to downy mildew disease did well in the 700-800 mm annual rainfall zone, as did two other pearl millet lines in the 600-700 mm zone. Two other varieties showed promise for late planting.

Using animal traction for millet cultivation in Niger, ICRISAT scientists saved 10 to 30% of manual labor. Land preparation by bullock-drawn plows made for better seedling emergence and crop growth than prepa-



Farmer in Burkina Faso proudly displays his harvest of an ICRISAT developed sorghum variety

ration by manual labor, and gave higher yields of grain and fodder.

Preliminary forestry studies by an ICRISAT cooperator from Texas A&M University, USA, in the Guesselbodi Forest region in Niger have shown that regeneration of vegetative cover on bare areas within a forest can be promoted by simple techniques. Branches from commercial wood harvesting operations used as a mulch lower soil temperatures, attract termites—which improve the surface soil structure, allowing rain to enter the soil—and thus promote vegetative growth.

If those findings are confirmed in further trials, a dramatically simple technique would be evolved to regenerate forests and improve the ecology of the region, which in turn could help arrest the advance of the desert and lessen the effects of recurrent drought.

Studying how farmers traditionally maintain the soil, ICRISAT scientists found that, as cultivation intensifies, farmers use organic fertilizer and crop rotation to maintain soil fertility, but soil structure is degraded, reducing entry of water into the soil.

Adding phosphorus fertilizer (P_2O_5) up to 24 kg per hectare was found profitable with traditional millet varieties on farmers' fields in Niger, provided the crop is planted on time and rainfall is sufficient to sustain adequate crop growth.

ICRISAT social scientists confirmed in comparative studies of Burkina Faso villages that as human population density increases, farming is extended to more marginal lands, fallow periods are reduced, and yields decline. By contrast, as intensified and improved production methods are used only

Mitigating Drought in Africa

Experience with recurrent drought in Africa indicates that while relief measures are helpful to an extent, they cannot mitigate the debilitating impact of long-term drought on a resource-poor agricultural base.

Some adjustment mechanisms help farmers cope with drought. Where pressure on land is low, families can migrate to nearby areas. Where family buffer stocks are maintained, those deprived can count on a share from those less in peril.

But as drought becomes more widespread and recurrent, these mechanisms fail. In addition to destroying land, drought wrecks the meager infrastructure that supports food and seed stocks, draft power, and labor.

Land dries up further and the soil hardens, making it more difficult to work and less productive. Undernourished men and animals cannot summon the energy required to farm the land again. Quite often animals die, or are sold or killed in times of acute stress. And seed crucial for continued farming has often been used as food to combat starvation.

Weeds abound when crops are not grown, as happens in years of acute drought. Weeding the entire area proves too difficult for the farmers, who leave parts of the fields unweeded. This reduces the area planted in subsequent years.

Drought also creates a dependence on external aid, straining the available administrative machinery and eroding the productive capacity of the local farmer. If food or cash relief is offered to the neglect of the local system's productive capacity, it perpetuates dependence and makes the farmer incapable of recovery even in post-drought years.

If such relief is to have any long-term impact, it must have built-in measures for reviving crop production. In this, the cooperative efforts of agricultural scientists who know the area, and relief agencies who have the funds and the will to help, are both critically important.

Advance provision will need to be made for stocks of seed and animal draft power to revive crop production when the rains return. Such seed will have to be protected against misuse: it could be eaten or sold for gain in times of stress. The seed must be adapted to local needs, and different varieties suited to good years and bad should be available. The active involvement of agricultural scientists and plant quarantine officials is important in planning such provisions and deciding when to release them.

Crop material needs to be diversified through multiplying improved seeds at better-endowed locations within the region. Relatively minor crops may be important locally, and will need to be given due weight in such efforts.

Fertilizer, especially phosphate, will be needed in most areas. Herbicides will be needed to help revive fields infested by weeds. Limited plant protection measures may save badly damaged crops.

All the needed inputs should be assembled before the cropping season commences. Any delay would reduce the revival capability of farming. Where tractors are available, they can be used by government to help till the land. Labor use under relief programs (such as food for work) can also be devoted to tillage, weeding, contour bunding, digging wells, and water harvesting measures.

All these measures involve extra costs, which relief agencies are often willing to help find. Some of the cost can be recovered from renewed crop production.

As drought creates a responsive or favorable attitude among decisionmakers, improvements in infrastructure and appropriate improved technology can be introduced in a timely and phased manner. The introduction of high-yielding rice and wheat in India over the last two decades is a case in point. Once such technology succeeds even in a limited area, its impact will spread to other areas.

Only a concerted and phased approach, backed by adequate infrastructure, can mitigate the hardships of drought. Reviving the farmers' ability to cope should be central to such an approach.

on lands with a higher potential, the gains that accrue are confined to those areas.

The social scientists also identified a wide range of local millets and sorghums sown by farmers at different periods in the Sudanian and Guinean zones. They quantified the potential for adoption of new varieties with specific growing periods, as substitutes for local varieties in late-planting situations. That information will be valuable as improved agriculture is introduced in those vulnerable areas.

Yield-gap trials, also in Burkina Faso, showed that deep plowing and tied ridging contribute to better yields, explaining much of the production gap that often occurs between research stations and farmers' fields. But deep plowing requires animal power that the farmer may not always possess, and tying ridges consumes more labor.

Two regional workshops were held in West Africa—one on sorghum at Ouagadougou, Burkina Faso, and the other on pearl millet at the ICRISAT Sahelian Center. They brought together many scientists from national and regional programs to review ongoing research and plan future strategy. The network of relationships formed should help ICRISAT to expedite crop improvement work in the region.

ICRISAT has thus been able to address some of the problems specific to the Sahel, even as it has been working to improve its mandate crops and the farming systems in that region.

Research organizations such as ICRISAT can only illustrate the potential that exists in a given environment. How far this potential is realized will depend on the cooperative efforts of national governments, relief and administrative agencies, extension workers, local agricultural and plant quarantine officials, and farmers.

The acccunt on the page opposite summarizes a paper that emerged from discussions among ICRISAT scientists with first-hand experience of working in Africa. It portrays the plight of many farmers in the

An interesting local sorghum from northern Mali.

Sahel. ICRISAT's efforts need to be viewed in that context. It is heartening that studies on problems caused by drought in sub-Saharan Africa over the last decade by the World Bank, the Food and Agriculture Organization of the U.N. (FAO), and the Organisation for Economic Cooperation and Development (OECD), all seem essentially to agree on what the mitigating strategy should be.

Working within that overall framework, ICRISAT fully expects to contribute its scientific expertise and skills to improving crop production in the Sahel, in active cooperation with scientists, administrators, and extension workers of the agencies concerned and the countries affected. Given the magnitude and the gravity of the problem, the effort has to be international, backed by local expertise on specific issues.

ICRISAT Lines Released and in Advanced Testing

Crop improvement is a time-consuming process. It often involves 5 to 7 years of basic breeding research and further years of national testing (5 or 6 years in India, for example) before newly developed varieties or hybrids can be released to farmers.

In several instances, ICRISAT has shortened this lag by entering promising breeding lines in cooperative trials with national programs, thus enabling them to study the performance of ICRISAT lines before release to farmers, a decision that remains the prerogative of the concerned national program.

During 1984, sorghum ICSV 1 (SPV 351) and pearl millet ICMS 7703 were released in India. ICSV 1 can be grown wherever sorghum is grown as a rainy-season crop in India. Several other ICRISAT lines in all of its

ICRISAT scientist in Mexico identifies lines for producing hybrids suited to the highlands and lowlands of South and Central America.

Farmers at Kamboinse, Burkina Faso, viewing a field of improved ICRISAT sorghum.

crops performed well in advanced national trials in India and moved a step closer to release. For example, pigeonpea ICPL 87 and chickpea ICCC 32 have already been identified as promising, and the pigeonpea will likely be released in 1985.

ICRISAT sorghums have done exceedingly well in Latin America and the Caribbean, where two ICRISAT scientists located at our sister institute for wheat and maize, CIMMYT, in Mexico, work on sorghum. A number of sorghums bred for low and intermediate elevations have made an impact in that region. Two varieties have been released in El Salvador, one in Honduras, one in Mexico, one in Nicaragua, and two in Venezuela. In addition, two varieties are nearing release in Guatemala, as is one in Honduras, which is performing even better in tests than the ICRISAT variety already released there. Seed of a promising line is being multiplied for use in Haiti.

A highland, red sorghum variety with cold tolerance, VA 110, has been released in Mexico. Because of high tannin content, it cannot be used for human food; but as it mixes well in animal feed, it frees for human consumption maize that would be otherwise used in animal feeds. A white-seeded variety, suitable as human food, is in final stages of testing with Mexico's national program.

An ICRISAT sorghum, SEPON 80-1, was released in 1984 in the Yemen Arab Republic, where two other lines are also doing well. In India's multilocational testing network, two ICRISAT sorghums gave good yields and moved nearer release, and a third was chosen for similar prerelease tests. Some other ICRISAT lines performed well in regional trials in East Africa.

In Sudan, ICRISAT sorghum hybrid Hageen Durra 1 did well during the drought

this year, and its seed is being multiplied on a large scale at the initiative of Sudanese agricultural officials. Under irrigation, Hageen Durra 1 yielded 5190 kg per hectare, compared with 1110 kg produced by the local variety. Enough seed was produced to plant 50600 hectares in 1984, but the authorities want to plant it on 6 to 10 times that area in 1985.

Seeds of two ICRISAT sorghums were multiplied in Cameroon, based on 4 years of varietal adaptation testing by SAFGRAD at the Maroua research station of Cameroon's Institute of Agricultural Research. Sorghum 38-3, an elite selection from ICRISAT, gave stable yields in those tests, proving tolerant of the most prevalent pests and diseases. Its white grain and early maturity (95-100 days) were liked by farmers. The other variety, E 35-1, improved from an Ethiopian source, also has excellent grain quality and avoids grain mold.

Elsewhere in West Africa, seeds of two ICRISAT sorghums are being multiplied. Framida, a variety developed from ICRISAT's germplasm collection, which is resistant to the parasitic weed *Striga*, is being grown in Burkina Faso and Togo, and ICRISAT's ICSV 1002 in Burkina Faso. Farmers' tests with ICSV 1002 in Burkina Faso showed good yield stability under drought.

Pearl millet ICMS 7703 was released in India in 1984, but commercial quantities of seed will be available only in 1985. A pearl millet released 2 years earlier, WC-C75 (ICMV 1), is being cultivated in most millet-growing areas of India, and has yielded well, showing a high degree of resistance to downy mildew. That variety has also been released in Zambia as ZMV 1 and is being considered for release to farmers in the Yemen Arab Republic.

Two millet varieties developed from ICRISAT material were recommended for release in Senegal, where two varieties released earlier—IBMV 8001 (ICMV 2) and IBMV 8004 (ICMV 3)—continued to yield more than 20% above the standard, Souna III. Both varieties were planted on more than 1000 ha in 1984, a significant coverage for

Hybrid sorghum nursery in Wad Medani, Sudan. An ICRISAT sorghum hybrid, renamed Hageen Durra 1 and released in Sudan, did well despite drought. Its seed is being multiplied on a large scale.

Seed of a newly developed dwarf pearl millet variety being multiplied in Senegal, where ICRISAT varieties are faring better than local cultivars.

Senegal. Farmers' wives reported that the improved varieties produced more couscous (a steamed preparation) and tasted better than local varieties.

In Sudan, the ICRISAT-developed pearl millet Ugandi escaped severe drought conditions because of its earliness and gave much higher yields than local cultivars. More seed is being produced to meet farmers' demands.

Several male-sterile pearl millet lines from ICRISAT have been distributed to breeders in the Indian national program for use in producing new hybrids. Male-sterile line 81 A is being extensively used by breeders in the Indian program, and we expect the more recently developed lines to gain wide acceptance.

Cyprus released chickpea ILC 3279, a kabuli cultivar highly resistant to ascochyta blight, from the ICRISAT-ICARDA program in Syria. Syria is also considering release of that variety because of its cold tolerance. Two other ICRISAT chickpea varieties did well in advanced testing in Nepal, as did another in Bangladesh. They are now being considered for release in those countries.

In India, where chickpeas are tested by geographical zones, an ICRISAT entry was the best in the northwestern plains, and another held its top position for the second year in the peninsular zone.

Pigeonpea ICPL 87, an early-maturing line with large seed and wide adaptability, is being multiplied in Maharashtra state, India, for possible release there. In agronomic tests at ICRISAT Center to maximize the yield of this multiple-harvest line, two harvests produced 3.8 tonnes per hectare of seed. A medium-maturing line, ICPL 270,

Above: ICRISAT pigeonpea ICPL 87 growing on a farmer's field in Andhra Pradesh, India, in a collaborative experiment with the All India Coordinated Research Project for Dryland Agriculture. Below: chickpea ILC 3279 (left), developed by ICRISAT and ICARDA scientists in Syria, resists ascochyta blight, which killed the line at right. It has been released to farmers in Cyprus.

gave the highest mean yield in trials over nine locations in India.

ICRISAT groundnut selection ICGS 11 moved a step forward in advanced pre-release testing of postrainy-season cultivars in India, and several ICRISAT lines moved ahead in earlier stages of testing as rainy-season cultivars. In tests of large-seeded confectionery groundnuts, grown under optimum conditions in India in the postrainy season, an ICRISAT line yielded more than 6 tonnes per hectare.

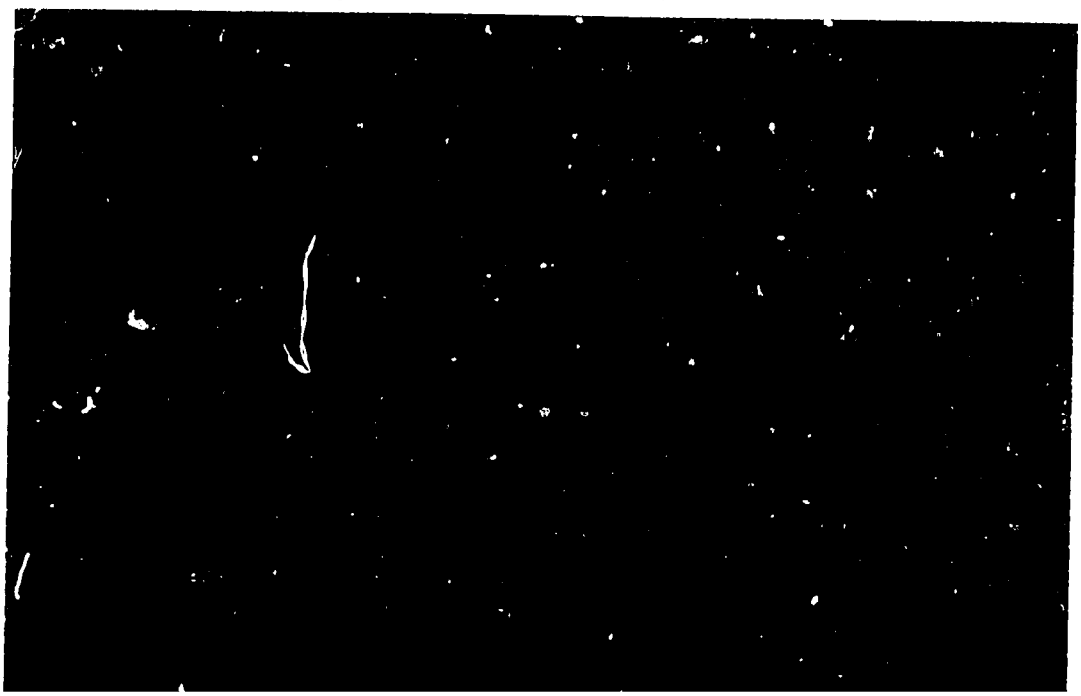
Added to the lines, varieties, and hybrids already released in earlier years, the 1984 developments can make a substantial impact in all parts of the world where ICRISAT crops are grown. Others are on the way. But an even greater impact is already being made by the varieties and hybrids that national programs have adapted from the ICRISAT breeding materials supplied to them.

Enduring Physical Stresses

Crops growing in the semi-arid tropics have to endure harsh environmental stresses—drought, high soil and air temperatures, poor soils, sandstorms, soil salinity, and highly variable rainfall. ICRISAT scientists study crop behavior under those conditions to identify crops and genotypes better adapted to such stresses. They also try to evolve farming systems and agronomic practices that can help the farmer cope with those marginal conditions for agriculture.

ICRISAT's past efforts yielded results this year in crop varieties that did well under drought stress in several countries, as

A drought screening trial with groundnuts at ICRISAT Center.



reported in the first two sections of this publication. But with an eye on the future, this year's work focused on identifying genotypes that could withstand more extreme stresses, under both natural and simulated conditions, and on adapting successful varieties for a wider range of environments.

Laboratory and field techniques were improved at ICRISAT Center for screening seedling emergence of sorghum and pearl millet at high soil temperatures and low soil moisture, a valuable asset in drought-prone areas. The laboratory technique enables the investigator to simulate a natural pattern of soil surface temperatures, while maintaining adequate moisture for germination in the seed zone.

Several sorghum lines were screened systematically in India and Mali, and a biochemical method of screening for ability to emerge at high soil temperatures was developed in collaboration with the Welsh Plant Breeding Station in the UK. The method enables us to study the ability of sorghum embryos to synthesize protein at high temperatures, an essential factor in helping seedlings to germinate and grow.

Germplasm accessions and breeding lines in sorghum were screened also for emergence through a soil crust, another helpful factor against drought. Studies on pearl millet under stress confirmed the crop's remarkable ability to adjust to drought before flowering, without much yield loss.

Poor crop establishment in a millet field at Sadoré, Niger, indicating the problems of crop growth in that region.

Salinity, seen here in Hisar, northern India, restricts crop production in some parts of the semi-arid tropics.

In field testing at ICRISAT Center, drought-resistant characters were found in 28 sorghum lines of varying origin, of these 3 have a good agronomic background, including ICRISAT hybrid SPH 225.

Promising drought-tolerant chickpea lines were identified for specific growing conditions in peninsular India which may be applicable for spring-sown chickpea in West Asia. To strengthen screening against drought, lamps that artificially extend day length in the field were used to synchronize flowering in genotypes differing in time to maturity.

ICRISAT scientists have also identified chickpea lines that abort fewer flowers and set more pods at temperatures approaching freezing. This could have the impact of increasing yields of chickpeas growing through subtropical winters, such as in northern India.

Work using extended daylengths also began in pearl millet to identify lines that flower at the same time even when daylength is varied. This will enable scientists to produce lines with wider geographic adaptation. In groundnuts, initial information has been obtained in collaboration with the University of Bonn to enable scientists to rapidly identify photoperiod adaptation in different cultivars.

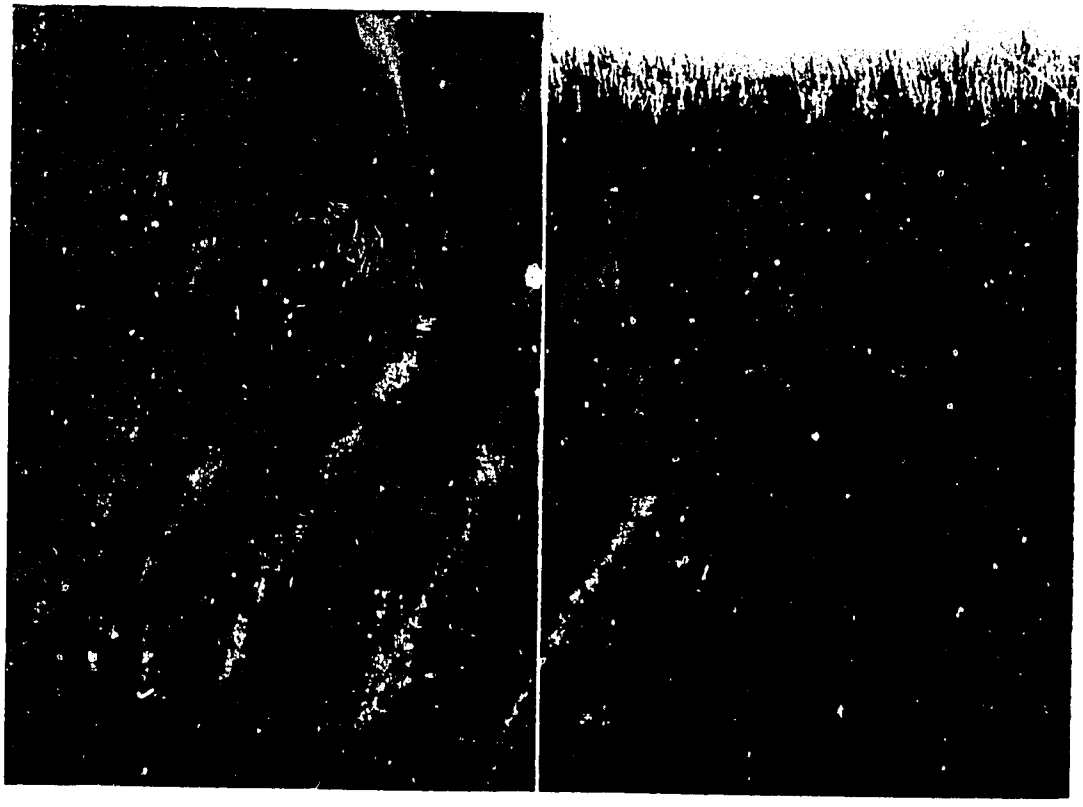
A pot technique was developed to screen large numbers of pigeonpea genotypes for tolerance of soil salinity, another important constraint on pulse production in many parts of the semi-arid tropics. Similar studies are already in progress for chickpea. A consultants' meeting was held, involving 30 ICRISAT scientists and participants from five countries, to evolve a strategy for future research on physical stresses faced in the production of both chickpea and pigeonpea.

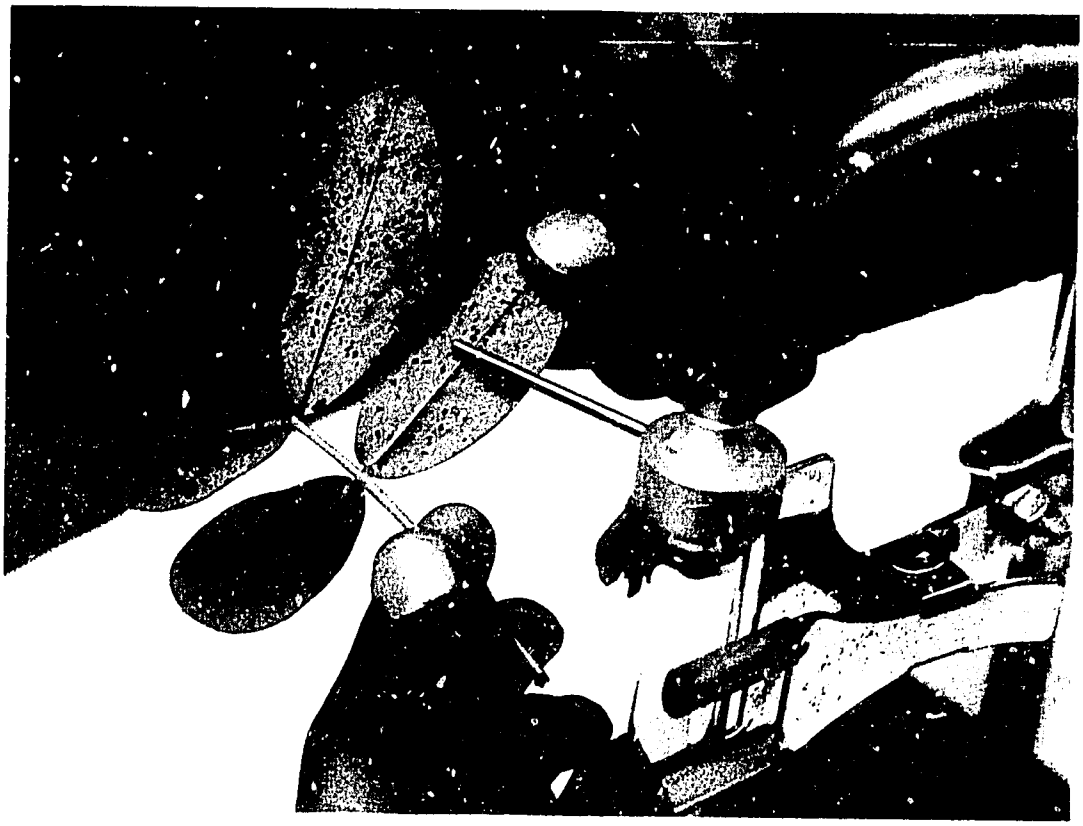
Developing Disease Resistance

Diseases are a major constraint to crop production. The typical farmer in the semi-arid tropics has very limited means to counter them. ICRISAT's work on developing crop resistance to diseases has many facets:

- studies on occurrence of diseases;
- identifying pathogens or disease-causing organisms;
- studies on survival and spread of pathogens under various conditions;
- developing techniques for screening genotypes both in the laboratory and in the field under induced disease pressures for levels of resistance;
- identifying sources of resistance to one or more diseases;
- testing stability of resistance over a range of locations;
- understanding genetic inheritance;
- breeding for resistance; and

Downy mildew in pearl millet causes leafy growth (left) instead of grain. At right, a resistant line grows well beside a susceptible one killed by the disease.





Spores are collected in screening efforts against groundnut rust disease

- testing advanced breeding lines for adaptation and yield levels

As reported over the last 2 years, ICRISAT now has lines with multiple resistances in all its crops. During 1984, for example, the ICRISAT Plant Materials Release Committee named four pearl millet lines with stable and combined resistance to three major diseases—ergot, smut and downy mildew—as an aid to breeders in national programs.

Investigations of multiple disease resistance in pigeonpea led in 1984 to identifying some lines with combined resistance to as many as four diseases. In similar work with chickpea, combined resistance to wilt—a major disease—and two different root rots was identified.

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

ICRISAT's smut-resistant pearl millets ICMS 8283 and ICMV 82132 continued to perform well in 1984 advanced trials in India and in several African countries, showing stable resistance to downy mildew and smut diseases and giving high grain yields.

In trials at nine locations in peninsular

Screening pigeonpea lines for resistance to sterility mosaic disease

India, two ICRISAT pigeonpea lines—one with resistance to wilt and the other to sterility mosaic disease—yielded more than the commonly grown C 11.

Work on identifying new sources of resistance and confirming known ones continued. In sorghums, the resistance to charcoal rot observed earlier in ICRISAT variety E 36-1 was confirmed under severe disease pressure, induced by withholding irrigation at different stages of crop growth during the dry season at ICRISAT Center. Resistance to sorghum downy mildew was identified in 47 lines of diverse origin and characteristics.

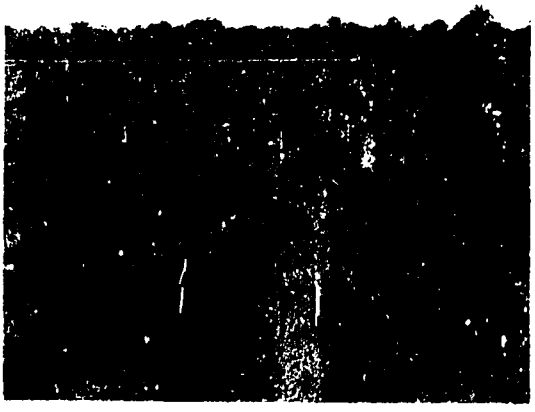
The ICRISAT Plant Materials Release Committee also named for use by breeders in national programs five pearl millet lines with stable resistance to downy mildew, four to ergot, six to smut, and seven to rust. In screening for downy mildew reactions, 50 of the 3000 pearl millet accessions screened showed a high level of resistance, and these were improved agronomically by selection. A new source of resistance to rust disease of pearl millet was identified; it is inherited through a single dominant gene, which will simplify resistance breeding.

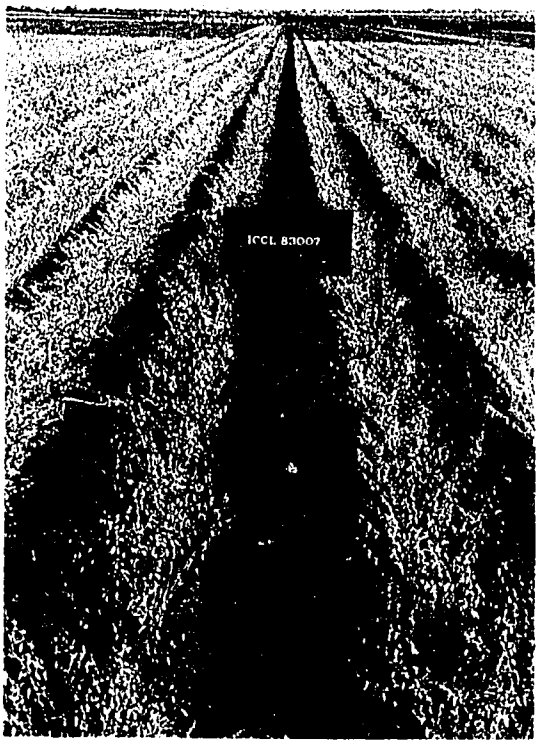
ICRISAT chickpea scientists have now identified 128 wilt resistant lines. They also found in continued pot studies that the wilt fungus can survive for 72 months in the soil. Because wilt is a major disease of chickpea, the new information will be valuable in further research.

Serious losses in groundnut are caused by a toxin-producing fungus, *Aspergillus flavus*. In research this year, a new breeding line was identified with better resistance to this fungus than the previously identified best

Early leaf spot damage in Malawi, where intensive screening has so far failed to identify resistant lines

Below, a wilt-sick plot, at right, a chickpea that resists wilt and gives good yields





resistant cultivar.

Rust, early leaf spot, and late leaf spot are the three most serious diseases of groundnut worldwide. In continued screening against those three foliar diseases, 50 lines with resistance to rust were identified; these will be screened further. Screening for resistance to early leaf spot was given high priority in southern Africa; but no line with a useful level of resistance could be identified in the 2000 tested this year.

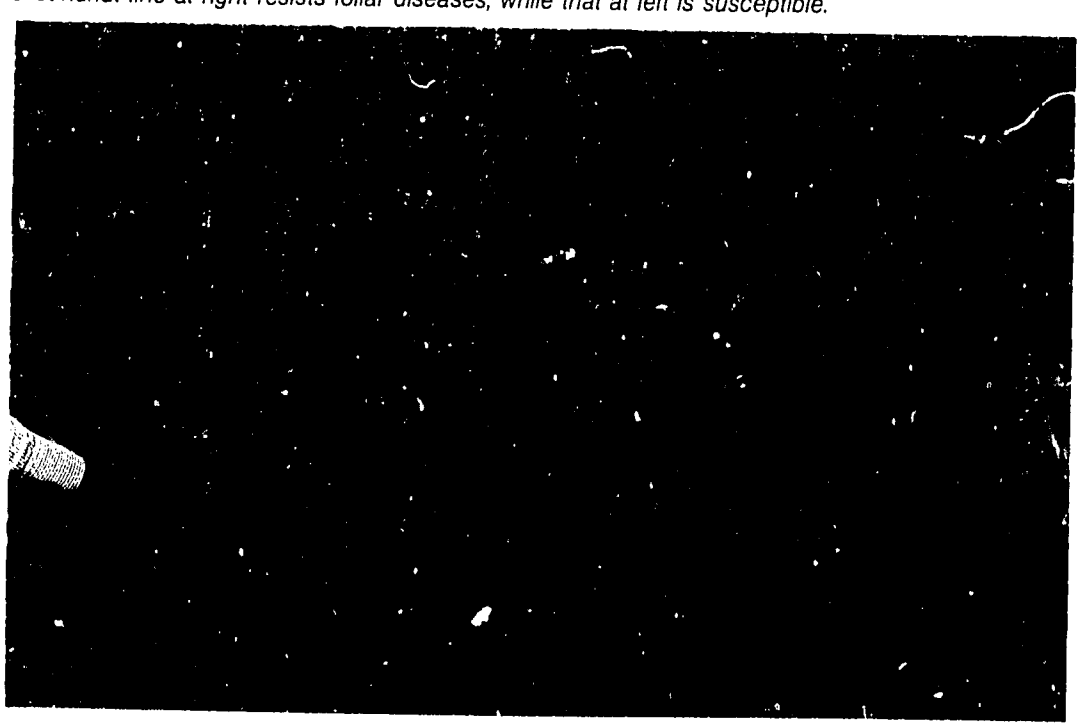
Phytophthora blight is a major disease of pigeonpea, caused by a fungus. Epidemiological studies at ICRISAT Center showed that wind and splashing rain contribute to spreading the fungus in the field. Preliminary studies also showed that a species of mycorrhiza can reduce the incidence of phytophthora blight.

Rosette virus disease is another major problem specific to groundnuts in Africa. Analysis of seasonal rosette development yielded valuable information that will be used to design rosette screening nurseries. Equally valuable information to help identify and detect the two viruses causing rosette was developed in collaboration with four institutions in Nigeria, Scotland, West Germany, and the USA. Experiments using this information have begun in Malawi and Nigeria to study the survival and spread of the disease and to improve control measures.

In another collaborative effort with the U.S. Grain Marketing Research Laboratory at Manhattan, Kansas, an improved assay technique was successfully used to evaluate sorghum lines for resistance to grain molds.

Progress made in earlier years with disease resistance work was thus carried forward effectively in 1984. The new techniques developed for screening, and the sources of resistance identified, should lead to more substantial results in the future, when resistant lines will likely be adapted and grown by larger numbers of farmers.

Groundnut line at right resists foliar diseases, while that at left is susceptible.



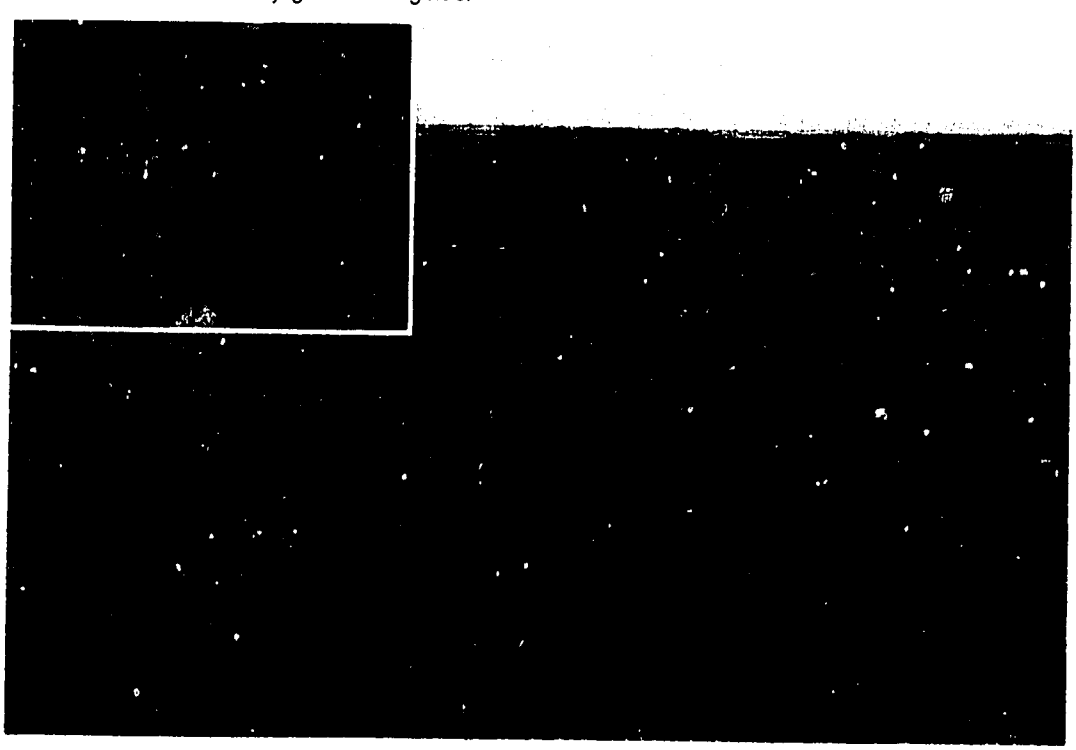
Controlling Insects and Weeds

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

Progress was made on all these fronts during 1984. The pod borer, *Heliothis armigera*, seriously damages pigeonpea and chickpea. In chickpea, breeding lines with combined resistance to *Heliothis* and fusarium wilt disease nave been identified. Studies were intensified both on natural enemies and on chemical control. Some promising parasites were identified, and chemical control methods were devised for low-input farming systems.

ICRISAT pigeonpea ICPL 84060, identified as tolerant to *Heliothis* , outyielded the commonly grown cultivar C 11 in India, with and without pesticide protection. By predicting the optimum times for spraying pesticides and by developing two improved sprayers (see page 33), ICRISAT scientists

The chickpea at left is damaged by the pod borer, Heliothis armigera *(inset). At right, with many more pods, is a resistant variety grown alongside.*



Differences in damage by the leaf miner to groundnut Robut 33-1. The dark green areas were protected by insecticide.

helped farmers in India reduce the number of sprays required for *Heliothis* control from four or more a season to two or three.

In work to correlate local host plants and environmental factors with *Heliothis* populations, data from a network of 113 pheromone traps set up at 60 locations in India, Bangladesh, Pakistan, and Sri Lanka, have been studied in collaboration with the Tropical Development and Research Institute, UK.

The podfly is another important pest of pigeonpea. Several genotypes were identified this year with podfly infestations consistently lower than the commonly grown cultivars.

In groundnuts emphasis now is on determining levels of pest populations at which damages occur, so that the breeding effort is not wasted on selection of lines resistant to insects that do not significantly reduce yields. Special attention is being paid to two caterpillars, the groundnut leaf miner and *Spodoptera litura*.

Four multiple-pest resistant and high-yielding groundnut lines are under initial evaluation at 25 locations in India. Genotype NC Ac 2230 was identified as the best general combiner for inheritance of trichomes that help resist jassids, a major pest. Under nonsprayed conditions at ICRISAT Center, groundnut lines resistant to thrips (another insect pest) and jassids significantly outyielded the check cultivars.

Groundnut ICG 2271 has resistance to several pests such as jassids, leaf miner, pod scarifying termites, and the thrips that transmit the virus that causes bud necrosis disease. It has outyielded the national check M-13 at several locations in India, and has been recommended as a pest-resistant parent in breeding activities of the Indian national program.

ICRISAT scientists have found resistance to the leaf miner in 20 groundnut lines. Some of those lines are also resistant to rust disease.

Midge is an insect that attacks sorghum. In ICRISAT's efforts during 1984, factors associated with midge resistance were identified. A midge-resistant breeding line, ICSV 197

(PM 11344) continued to do well against midge attack in intensive screening tests.

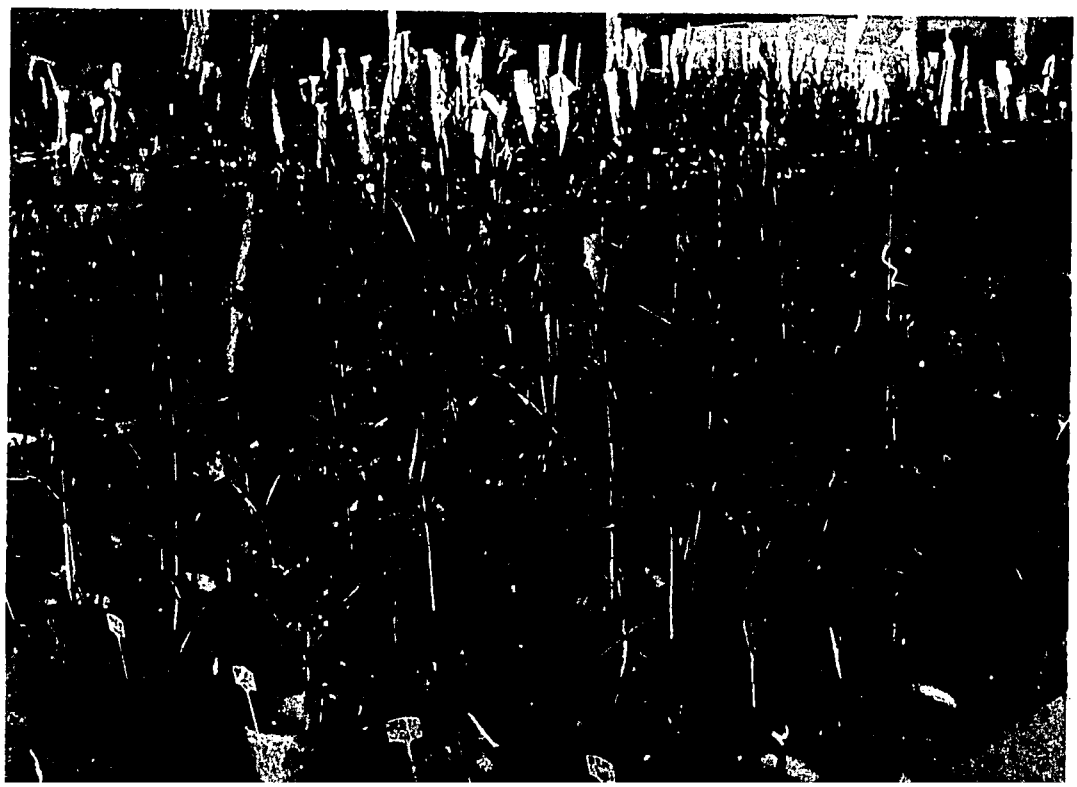
Screening in cages was standardized for resistance to shoot fly—another sorghum pest—under controlled conditions, where insect populations are kept constant and genotypes are exposed one at a time. And a laboratory technique was improved to rear stem borers, so that large numbers of sorghum plants can be artificially infested to help in resistance screening.

Insects can act as carriers of plant diseases, as with aphids that cause stunt disease on chickpea by acting as a major vector of pea leaf-roll virus. Studies on aphids have begun. Work continues on thrips, which act as vectors of bud necrosis disease in groundnut.

ICRISAT scientists have identified seven species of nematodes (eelworms) that parasitize chickpea roots. Work began also on pigeonpea nematodes, with emphasis on screening for resistance to a cyst nematode.

Sorghum head at left is damaged by midge (inset), while the one at right resists the insect.

Pot screening at Kamboinse, Burkina Faso, against Striga, *a parasitic weed that reduces sorghum and millet yields.*



Most of ICRISAT's work on weed resistance has focused on *Striga*, a weed that reduces yields in both sorghum and millet. A *Striga*-resistant sorghum variety, SAR 1, has successfully completed 2 years of on-farm testing in endemic areas of Maharashtra, India. In Burkina Faso, a few sorghum lines developed from ICRISAT material have shown high levels of resistance to *Striga* and maintained their yields under pressure. Similar tests there with pearl millet have identified four lines with reduced *Striga* incidence (90% less than the check variety).

Orobanche is a parasitic weed that reduces yields of winter-sown chickpea in West Asia and the Mediterranean. Eleven resistant lines and 170 tolerant ones have been identified in field screening and are being included in breeding activity at our cooperative program with ICARDA in Syria.

Crop damage by insects in India alone is estimated to cost US$ 650 million annually for the five crops in ICRISAT's mandate, illustrating the need for continued research to improve control of insect and weed pests.

Augmenting Genetic Resources

During 1984, ICRISAT's Genetic Resources Unit added 4975 new accessions of its mandate crops, and 408 of minor millets, to its gene bank. And a total of 64988 seed packets were distributed—35298 to ICRISAT scientists, 8914 to scientists in India, and 20776 to those in 57 other countries.

Collecting, conserving, and distributing such accessions is crucial if crop improvement work is to have an impact in different parts of the world. The Institute's total collection now exceeds 80000 accessions.

A significant advance was made during 1984 in the program to convert some exotic sorghum landraces into more usable breeding lines.

ICRISAT's collection of 24000 sorghums consists largely of very tall landraces that are photoperiod sensitive, a trait that limits their use in breeding programs. Over the past few years, ICRISAT scientists have converted eight Zera-zera landraces from Ethiopia and Sudan, which have disease resistance and excellent grain quality, into lines that are insensitive to photoperiod and will flower and produce grain no matter how many hours of sunlight there are in locations where it is grown.

For this, they adapted a technique originally developed at Texas A&M University, USA, and used a process called backcrossing, which involved breeding through many generations and took up to 6 years. That work is now complete with Zera-zera sorghums.

The resistances present in the landraces thus become available to breeders. Thousands of selections from partially converted sorghum lines have been made by scientists from ICRISAT, the Indian national program, and in-service trainees from 13 countries.

Conversion of other sorghum landraces from Nigeria, with desirable traits, has begun. Screening for photoperiodic insensitivity in pigeonpea has identified some new sources.

Another 1984 development was the collection from highlands in the Yemen Arab Republic of sorghum races Durra and Durra-

Sorghum converted to photoperiod insensitivity yields well (foreground), while landraces (background) show little grain

caudatum with large, compact panicles and big grain.

A collection mission with the national program of Brazil and the International Board for Plant Genetic Resources (IBPGR) yielded 73 samples of wild and cultivated groundnut, which are being transferred to ICRISAT's gene bank. They could be an important source for the transfer of resistant genes from wild relatives of groundnut into adapted cultivars.

To fill important gaps in our chickpea collections, 824 new lines were imported from the USDA Gene Bank, Washington, USA. The base for disease resistance in chickpea was broadened by 129 new accessions collected from Ethiopia, where past accessions have shown better distribution of disease resistance.

Accessions of all mandate crops have been distributed in many countries. In pigeonpea, for example, 69 countries have so far received ICRISAT accessions.

A number of pearl millet accessions from Burkina Faso, Ghana, India (three states represented), Malawi, Sudan, and Zambia were classified into landrace groups by morphological and agronomic traits. A key was developed for identifying the accessions.

Comprehensive data, including plant origin and characterization, already stored on computer for nearly 14000 chickpea accessions, are now being used to meet requests for seed. Similar data were stored on computer during 1984 to aid retrieval, on request, of over 10000 accessions of pigeonpea, 10000 of groundnut, and 5000 of sorghum.

Exploiting Available Nutrients

In the complex interaction of natural forces, some bacteria or fungi can help plants to exploit air and soil nutrients, grow better, and yield more food. ICRISAT scientists work on identifying these and on finding ways to use them for crop production.

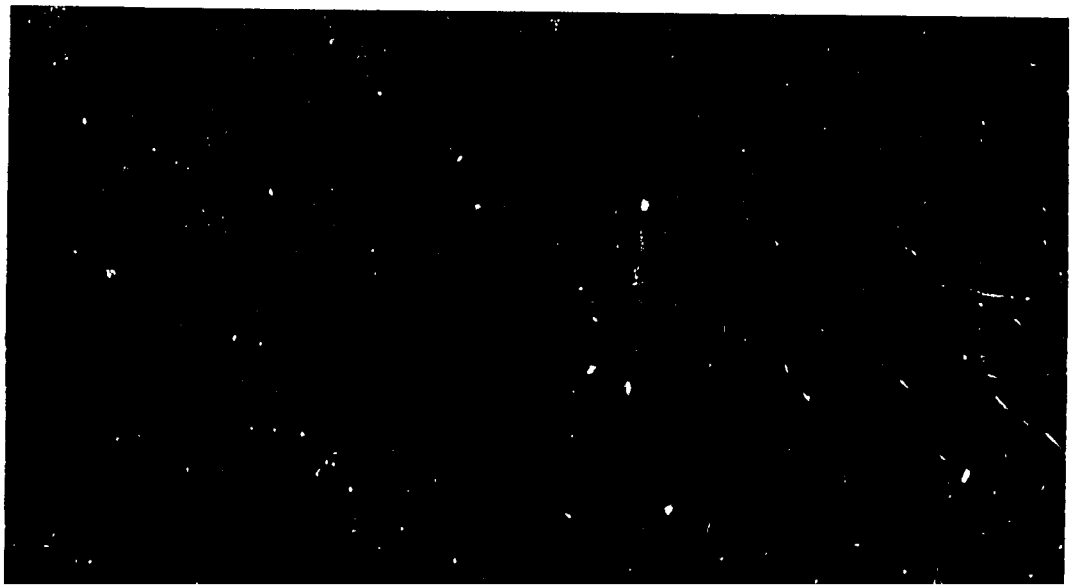
Last year, two strains of *Rhizobium* bacteria identified by ICRISAT scientists had been recommended to inoculant manufacturers in India, to help farmers exploit nitrogen from the air for better crop growth. One strain was for chickpea, and the other for pigeonpea. During 1984, another strain similarly identified for groundnut, NC 92, has gone into commercial production in India.

Inoculation with rhizobia is far cheaper than adding commercial nitrogen. This method of increasing crop yields is only one aspect of ICRISAT's work that aims to minimize dependence on commercial fertilizer, the cost of which remains outside the reach of many small farmers.

In research on beneficial fungal strains associated with the root zone of plants, known as mycorrhizae, ICRISAT scientists preliminarily established that inoculation with one such fungus can at least double the growth of pigeonpea plants in sterilized soil. They had established a similar trend in a series of pot trials in earlier years with sorghum and pearl millet. They have also found that inoculation of pearl millet by mycorrhizae enhanced plant growth and phosphorus uptake in soil fertilized by rock phosphate. The potential of these findings will be tested further.

Continued studies on nitrogen fixation showed that chickpea can derive almost 90% of its nitrogen requirement from the air; this equals about 40 kg per hectare of applied nitrogen fertilizer. The intact-plant tube assay technique was successfully used in the laboratory to screen strains of nitrogen-fixing bacteria that can benefit pearl millet plants. In field trials also, positive yield responses were observed in pearl millet cultivars to inoculation with nitrogen-fixing bacteria.

In a field trial, groundnut cultivar at center fixes nitrogen from the air and grows well, while the line at left does not. The sorghum at right fixes negligible nitrogen by comparison.



Modeling Crop Response to Weather

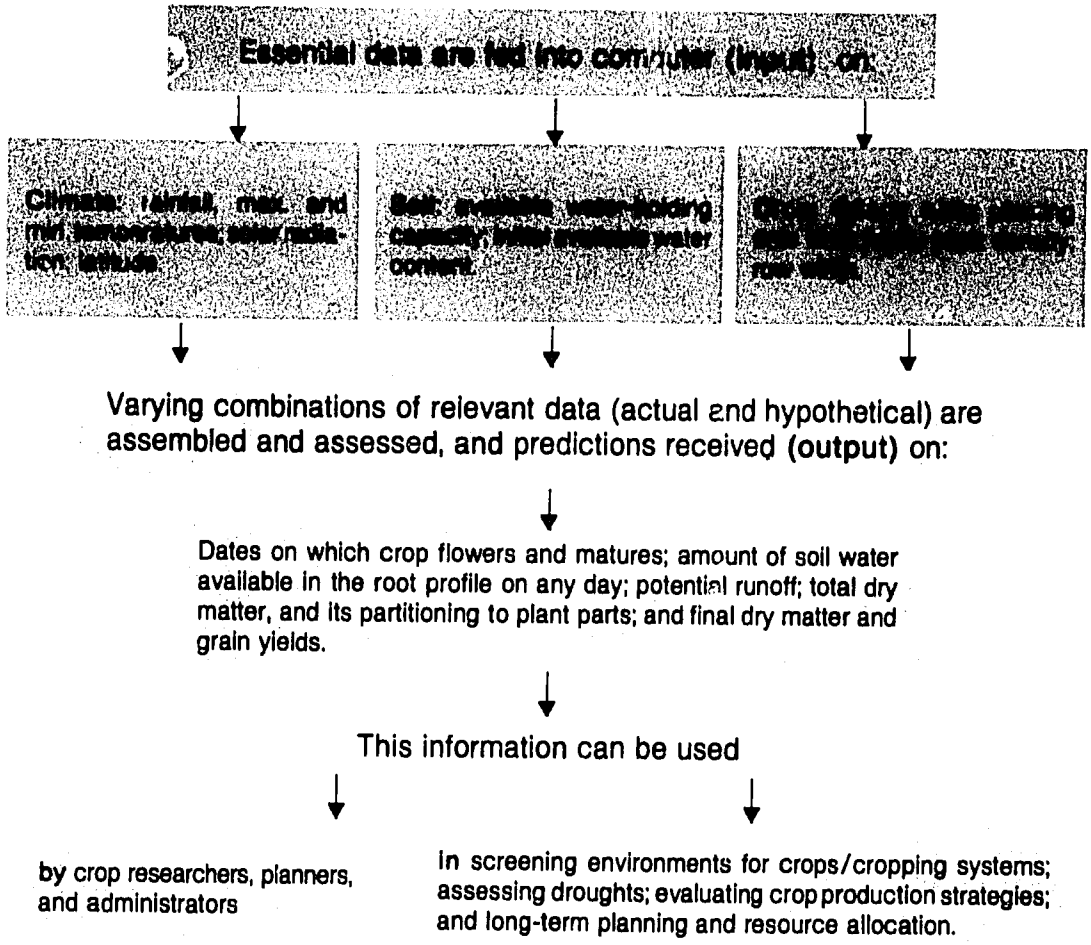
An important research component in transfer of technology is the ability to predict how crops will behave in a range of natural environments. ICRISAT scientists work on simulation models that help improve such forecasting capability.

Simulation models attempt to imitate the processes of crop growth, based on physical laws and biological responses to environment, and using weather, soil, and crop data. They clarify the existing knowledge about crops by arranging it in a systematic form, and help design relevant experiments.

Crop weather modeling has wide application. It can be used—as it has been by ICRISAT scientists—to suggest not only the most suitable crop for a given location or season, but also such specific issues as optimum sowing date, best date(s) for applying irrigation where required, fertilizer levels, etc., and

ICRISAT scientist explains experiment on crop modeling to participants in a 1982 symposium, cosponsored by WMO, ICRISAT, and three other organizations. They came from 18 countries.

How Crop Modeling Works



to predict yields under varying stress conditions. Management decisions on remedial steps can thus be planned in advance. Crop models can illustrate the full potential of available soil, rainfall, and inputs. And they aid researchers and administrators in making decisions on resource allocations.

Based on 5 years of multilocational experiments, scientists at ICRISAT Center have been able to revise a sorghum model initially developed in 1976 at Texas A&M University, USA, to make it more effective and precise in forecasting the crop's behavior in the semi-arid tropics.

When field experiments in 1979/80 and 1980/81 showed gaps between projected and actual results, several subroutines of the original model were revised, based on collaborative testing at eight locations in India, and one in Thailand.

The gap between simulated and actual results narrowed considerably after the model was revised. Tests with data from subsequent years showed that the model had improved its capability for forecasting. It computed more successfully the effects of drought stress and plant density on sorghum grain yields.

During 1984, ICRISAT scientists established—through comparing yields simulated by the improved model with actual yields obtained over 7 years in breeders' experimental plots at ICRISAT Center—that the model could predict sorghum yields within 10% of actual yields in all but one year, when the gap was 20%.

A similar model for pearl millet developed in 1982/83 was revised this year. Work has also begun on models for groundnut and chickpea, and this will continue. The emphasis at ICRISAT so far has been on single-crop models, but as the work progresses, new models can be evolved to match conditions in developing countries where several crops are often grown together on small areas.

An environmental physicist from the University of Nottingham, UK, spent 5 months during 1984 at ICRISAT Center, and developed a new model that links crop growth with water availability and rates of transpiration. The model is based mainly on data that are measurable and reduces reliance on assumptions.

Improving Farm Equipment

Designing or modifying farm equipment to help improve the efficiency of the small farmer is an important part of ICRISAT's farming systems work. This year, our engineers improved their design of a planter and fertilizer applicator unit, modified low-volume and ultra-low-volume sprayers for farmers using insecticides, and started work on Agribar, a cheaper alternative to the wheeled tool carrier.

In a 3-year project ending 1983, a mechanical planter and fertilizer applicator unit had been developed as an attachment to the bullock-drawn wheeled tool carrier. While the unit worked efficiently, it put too much strain on the bullocks normally used by farmers, and the necessity to use a tool carrier with the planter posed a cost constraint. Farmers voiced a need for simpler bullock-drawn equipment for sowing crops and applying fertilizer, independent of the tool carrier.

Such a piece of equipment was developed and tested during 1984 with both rainy and postrainy season crops at ICRISAT Center. Except for chickpea, which needed 20% more seed than expected, the planter provided good plant populations in all the crops. It also saved labor, and will now be tested on larger plots and on farms.

A set of drawings for the planter was made available to one manufacturer in India for

The improved planter and fertilizer applicator can operate on 4 rows at a time, and saves labor.

Ultra-low-volume sprayer, being used (above) by a farmer in Farhatabad village in Karnataka, India. It saves water and improves the efficiency of application. The traditional spraying method (below) uses large quantities of water.

Agribar: a simply constructed, lighter, and cheaper alternative to the wheeled tool carrier

limited production. Performance of the machines produced will be tested. Design drawings of improved farm machinery were also supplied to institutions and manufacturers in 25 other countries.

Another 1984 development was the adapting of low-volume and ultra low-volume sprayers to improve insect control by farmers. An ICRISAT entomologist had identified the need for such sprayers in his tests, and had begun work on it.

Conventional knapsack sprayers require 400 to 600 liters of pesticide solution per hectare, imposing a constraint on the farmer who has to carry clean water from a distance. The adapted units, mounted on the wheeled tool carrier and tested on pigeonpea crops, greatly reduce the demand for water.

Preliminary results showed that the low-volume sprayer used about 70 liters of solution per hectare, and the ultra low-volume sprayer only about 10 liters. The latter was tested in on-farm research in Karnataka state, India, with good results.

The cost of the wheeled tool carrier, an essential component of ICRISAT's recommended technology, is too high for most farmers. Our economists found that current prices in India exceed by 50% the price farmers would find reasonable; they synthetically computed a market price for the machine about 30% below present prices.

In response to this, ICRISAT engineers began work in 1984 on the Agribar. Lighter, simply constructed, and easy to handle, the Agribar aims to maintain the versatility of the tool carrier. Implements now used with the tool carrier would be usable with the new toolbar.

The current cost estimate in India for the Agribar is about Rs 1500 (US$ 120), while a wheeled tool carrier costs Rs 5400 (US$ 430). The toolbar is also being tested in field-scale experiments in West Africa; tests are under way in Mali and will be extended to Niger. It will also be tested on farms in India.

The tests of equipment have involved cooperation with national programs, and such cooperation will intensify with more pieces of new equipment. Rapport with manufacturers, established through providing technical guidance, offers us useful feedback on actual performance and use of the machines. We will continue to advise and monitor.

Village Level Studies

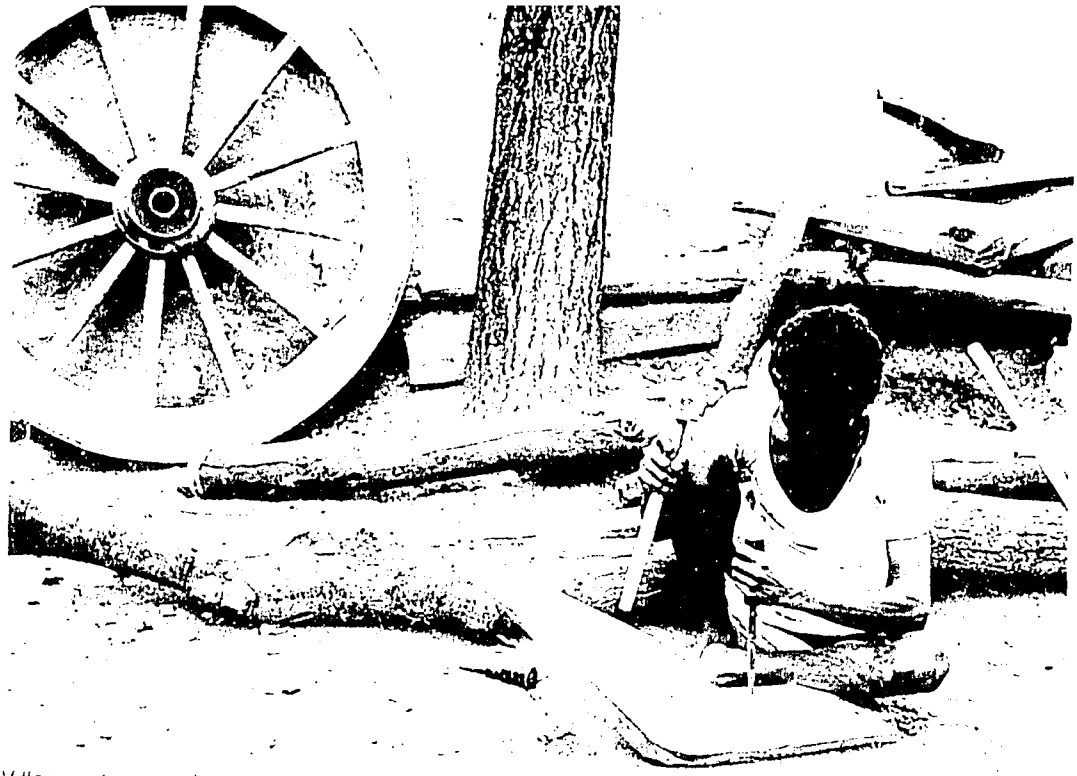
Over the last decade, ICRISAT economists have assembled a large body of information that can be critically important in deciding policies to help farmers increase and stabilize their agricultural production. Several aspects—behavioral as well as agroclimatic—associated with decisionmaking by farmers have been studied in detail, both to help evaluate technological options and to provide information relevant to policies on allocation of resources.

At the heart of this research effort are Village-Level Studies (VLS), which will be completed in 1985 in 10 Indian villages located in a range of agroclimatic environments. Six Indian villages—four in the state of Maharashtra and two in Andhra Pradesh—have been studied since 1975; two in Gujarat were added for study in 1980, and two more in Madhya Pradesh in 1981.

Similar studies undertaken in 1981 in 10 villages of West Africa (in Niger and Burkina Faso) will continue. The West African studies are designed to allow a greater role for on-farm testing and evaluation of technology.

Some of the villages in India have been studied in collaboration with local agricultural universities. A trained economic investiga-

Woman in Kolbila village, Burkina Faso, grinds millet grain for meal. ICRISAT social scientists try to understand food preferences of farm families.



Village artisan makes a traditional plow in Maharashtra state, India, from locally available material

tor with a rural background and local language fluency resides in each village and monitors and records agricultural activities of sample households—10 landless laborers and 30 farmers in each village. The investigators establish a cordial and relaxed relationship with the households and assemble information on agricultural practices and household conditions, which are added to a data base maintained at ICRISAT Center.

The investigators have been valuable also in on-farm tests of ICRISAT technology, and in monitoring results from such tests, because they act as participant observers. VLS data were used in designing the watershed approach to dryland farming in India, and the feedback from resident investigators helps modify the approach and improve the technology.

ICRISAT's socioeconomic research is developed in consultation with physical and biological scientists, and focuses on the village as the best source of information for analyzing constraints to agricultural development and designing means to alleviate them. The villages are chosen, on the basis of background information and detailed investigation, to be typical of varying agroclimatic zones.

Data on agricultural operations are collected on a plot basis. The information includes all inputs used, time allocated by each household member and pair of bullocks, crop and livestock production, economic transactions and prices, and capital endowment of each household. Intensive anthropological data were added to the studies in 1976, and studies on nutrition and health were carried out in 1977/78.

One village in each region is used as a control to measure the impact of substantial research efforts in the other villages.

The resident-investigator approach provides easy resurvey capability, and can be readily used for special-purpose studies, such as on consumption patterns of food and fuel, risk attitudes, cropping patterns and rotations, weed management, seasonal

Meal being prepared in an Indian village. Pigeonpea sticks are used as firewood

labor availability and wages, and rural income.

Some of the special studies apparently have had an impact on policy development, not merely in technology design or research-resource allocations, but also in the nature of governmental intervention.

A study on "slowly improving crops"—sorghum, pearl millet, chickpea, pigeonpea, and other pulses—had findings that can be related to recent announcements by the Government of India that more emphasis will be given to pulses, oilseeds, and dryland farming in general.

Another study found that crop insurance would prove more beneficial to poor farmers than price support. But for coarse grains, such as sorghum, both measures would benefit vulnerable farmers. The Government of India now has plans to introduce crop insurance, interlinked with credit supply.

The study added a caution that the potential benefits of measures to stabilize prices and yields must be weighed against their costs, including administrative costs, a finding that will be of increasing relevance as the measures are put into effect.

Based on its VLS experience, ICRISAT is preparing a monograph on the subject. In addition to over 40 special studies or research reports, some of which have been cited here, the data generated by VLS have already been used in some 12 M.Sc. and Ph.D. theses by scholars from eight countries. Requests for access to the data continue.

While the data generated by VLS have considerable potential for further use, their use by national programs has at times been hindered by the need to rely on sophisticated retrieval processes and a large computer system. Consequently, studies will now be done on a smaller scale, improving access by enabling easier handling of the data assembled. A proposed training course in 1985 will reflect this change, and draw on the experience of two ICRISAT economists from West Africa.

Training Activities

Training continues to be a crucial aspect of ICRISAT's work. Agricultural scientists and technical assistants from many countries come to the Institute each year to learn about ICRISAT's research and to improve their own skills. ICRISAT scientists posted elsewhere also offer research advice and training. More than 900 personnel from 69 countries have completed training since 1974, and many of them now serve as research leaders, farm managers, field technicians, and extension agents in national and international programs of agricultural improvement.

During 1984, 148 scientists, research technicians, and extension personnel from 39 countries participated in training programs at ICRISAT Center; another 27 students or trainees from nine countries worked with our scientists in Burkina Faso, Mali, Mexico, and Niger.

Three postdoctoral research fellows completed studies during the year, and 13 others continued studies. Among those who completed, one worked in Mali and at ICRISAT Center on drought tolerance and screening for plant establishment in pearl millet. The other two studied traits that influence resistance to insects in groundnut plants and pods, and breeding wilt resistance in chickpea, respectively.

The 13 who are continuing carried out research relating to on-farm studies, entomology, physiology, virology, and plant breeding programs. They worked on inheritance of factors associated with disease and

In-country training in the Dominican Republic.

Research scholar from Somalia (right) studying stem borer resistance.

insect resistance in groundnut, chickpea, and pigeonpea, and ways to improve crop management and production.

Nine in-service fellows—holding midlevel positions in national research programs in five countries—completed intensive short-term training (ranging from 1 to 12 weeks) in aspects of plant pathology, entomology, microbiology, and crop production systems.

As many as 32 university students from 12 countries worked as research scholars under the supervision of scientists at ICRISAT Center. Of these, 15 completed their training in 1984. They studied: screening for salt tolerance; physiological factors affecting growth and photoperiod response in groundnut; watershed management; water harvesting and groundwater hydrology; weed control; hybridization of wild and cultivated species; genetic inheritance of resistance to insects such as stem borer, shoot fly, and jassids; environmental influence on nitrogen fixation; nitrogen-fixing bacteria; handling of rhizobial strains and competition among strains; and marketing efficiency in the semi-arid tropics.

ICRISAT and associated scientists in Niger guided 11 students—from Belgium, Burkina Faso, Ivory Coast, Niger, and USA—on topics such as screening for heat tolerance, crop water balances, sources of nutrients for cropping systems, fertility management, influence of planting date on insect damage, and screening for insect resistance. Four B.Sc.-level students in Mali worked for their senior-year theses under

ICRISAT-staff guidance. Among the topics: photoperiod sensitivity of sorghum, effects of plot size on yield estimation, and comparison of isogenic red and tan sorghums. Similarly, seven students in Burkina Faso worked on genotype interactions, *Striga* management, stimulant influences, resistances, germination, and constraints to transfer of technology.

During 1984, 84-in-service trainees from 30 countries participated in individualized 6-month programs at ICRISAT Center. Their study programs covered crop improvement, crop production, and farming systems related to all mandate crops. Seven participants completed 4½ to 5-month training programs with ICRISAT and CIMMYT staff at Mexico. They worked on improved sorghum production, and were from Ecuador, Mexico, and Panama.

A total of 217 scientists, extension personnel, bank agricultural officers, and development officers or policymakers from four states of India were provided short-term

Former in-service trainee from Zimbabwe (center), who returned to ICRISAT Center in 1984, selecting sorghum germplasm with other scientists.

Trainee from Thailand uses a microscope to study thrips, watched by ICRISAT entomologist.

training. Their training focused on identifying suitable cropping systems for use on the broadbed-and-furrow system, and other factors associated with ICRISAT's technology for deep black soils being tested in the four Indian states of Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra.

A 5-week training course was held in 1984 for seven agricultural economists from Bangladesh, Burkina Faso, Indonesia, Kenya, Mali, Nigeria, and Sri Lanka. A broad range of subjects was covered, with detailed attention to questions on methodology, based on ICRISAT's experience with village-level studies. A similar course is planned in 1985.

ICRISAT scientists located in Burkina Faso, Mali, and Niger offered their expertise in short-term courses held by six national or regional programs in Africa.

Through its range of training programs, ICRISAT implements its mandate to assist in the development and transfer of technology to national programs across the semi-arid tropics.

In Other Research . . .

- A regional sorghum and millet improvement and training program was launched at Bulawayo, Zimbabwe, during 1984. Work on farm development and assembling crop nurseries for testing got under way. Links were established for evaluation of material at locations in Botswana, Malawi, Tanzania, Zambia, and Zimbabwe. Testing of lines began at Matopos research station and at a sewage farm in Bulawayo, where sewage treatment assures water for irrigation of precise experiments for breeding parental lines.

  Seeds of promising lines are being increased for use. The regional program has been set up in response to a request from the nine-country Southern African Development Coordination Conference (SADCC). The ICRISAT team there will eventually comprise seven principal scientists, a farm development specialist, and an administrative officer.

- ICRISAT's regional groundnut improvement program for southern and eastern Africa, based in Malawi, had outstandingly good regional yield trials. This reflects a rapid and significant broadening of the genetic base of groundnuts in the region. Trials at six locations—two each in Malawi and Zambia, and one each in Mozambique and Zimbabwe—helped identify 19 promising lines with sequential branching and 4 with alternate branching habits.

- In the population trials of the All India Coordinated Millet Improvement Program, varieties bred from improved cycles of the intervarietal and new elite composites from ICRISAT gave the highest grain yields.

- Through several years of selection for increased grain protein, ICRISAT scientists identified inbred pearl millet lines with 14 to 18% protein content, including superiority in total available lysine and digestibility, compared with 9 to 10% in normal genotypes.

- In breeding hybrid pigeonpea cultivars at ICRISAT Center, a male-sterile source was successfully used to backcross male sterility into 12 elite lines, thus broadening the agronomic base of female parents.

- A staggered harvesting system was established to determine early maturity in groundnuts. More than 300 breeding lines and accessions were screened, 60 in the postrainy and 250 in the rainy season.

- Operational-scale evaluation of cropping systems on three major types of soils in India's semi-arid tropics confirmed that pigeonpea-based intercropping systems gave the best and most stable returns.

- On-farm verification of ICRISAT's technology for deep black soils provided further evidence of the agronomic and economic advantages of the technology in the four states of India where verification studies have been under way. Economists monitoring on-farm variations in the adoption of that technology in Begumganj, Madhya Pradesh, found that farmers there got 106% average returns on added costs in 1983/84.

- Continued studies at ICRISAT Center confirmed that preventing trampling and puddling of the soil on broadbeds in deep black soils significantly improves the yields of two postrainy-season sequential crops—chickpea and safflower.

- Based on metereological data obtained from 58 stations in Burkina Faso, analysis of rainfall distribution was begun to identify the optimal growing zones for the staple crops of that country.

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B. C. G. Gunasekera, Principal Soil and Water Scientist (International Cooperation)
S. J. Phillips, Special Assistant to Director General for Educational Affairs
V. Balasubramanian, Senior Executive Officer to Director General
Joyce Gay, Senior Administrative Secretary to Director General
Sunetra Sagar, Administrative Secretary to Director of Research
S. Krishnan, Senior Administration Officer (International Cooperation)
D. Mitra, Fiscal Manager
A. Banerji, Assistant Manager (Fiscal)
V. S. Swaminathan, Senior Accounts Officer
A. N. Venkataswamy, Accounts Officer
C. P. Rajagopalan, Accounts Officer
B. K. Johri, Personnel Manager
Y. Bharadwaja, Assistant Personnel Manager
N. S. L. Kumar, Senior Personnel Officer
P. Suryanarayana, Senior Personnel Officer
R. Vaidyanathan, Purchase and Stores Manager
K. P. Nair, Senior Purchase Officer
D. K. Mehta, Senior Stores Officer
D. V. Rama Raju, Senior Purchase Officer
K. C. Saxena, Stores Officer
K. R. Natarajan, Shipping and Purchase Officer
S. K. Dasgupta, Senior Scientific Liaison Officer (Visitors' Services)
A. Lakshminarayana, Scientific Liaison Officer (Visitors' Services)
K. K. Sood, Senior Security Officer
A. Ekbote, Security Officer
S. Ramachandran, Administrative Officer (International Cooperation, from August)
K. K. Vij, Senior Administrative Officer (Delhi Office)
V. Lakshmanan, Assistant Manager (Administration)
N. Surya Prakash Rao, Resident Medical Officer
R. Narsing Reddy, Transport Officer (on study leave)
G. Vijayakumar, Transport Officer
K. Jagannadham, Administrative Officer (Transport)
K. V. S. Bose, Travel Officer (until October)

International Cooperation

ICRISAT Sahelian Center, Niger

M. Tardieu, Coordinator of Programs, West Africa (until December)
K. F. Nwanze, Principal Millet Entomologist and Team Leader
K. Anand Kumar, Principal Millet Breeder
B. B. Singh, Principal Millet Breeder, (Maradi)
M. V. K. Sivakumar, Principal Agroclimatologist
D. C. S. Spencer, Principal Economist (from May)
M. C. Klaij, Principal Soil and Water Engineer
C. A. Giroux, French Writer/Editor
B. D. Marvaldi, Project Development Officer (from May)
P. G. Serafini, Farm Manager (from April)
D. C. Goodman Jr. , Administrative Officer
L. K. Fussell, Principal Millet Agronomist
B. Christianson, Soil Scientist (ICRISAT/IFDC)
A. Batiano, Soil Scientist (ICRISAT/IFDC)
Maimouna S. Dicko, Animal Nutritionist (ICRISAT/ILCA)
E. J. Guthrie, Principal Millet Pathologist (until August)
J. McIntire, Principal Economist (until April)
B. R. Ntare, Cowpea Breeder/Agronomist (ICRISAT/IITA)
R. Chase, Soil Scientist (Texas A&M University)

Burkina Faso

C. M. Pattanayak, Principal Sorghum Breeder and Team Leader
K. V. Ramaiah, Principal Cereal Breeder—*Striga*
S. N. Lohani, Principal Millet Breeder
E. R. Perrier, Principal Agronomist, Soil and Water Management (until September)
P. J. Matlon, Principal Production Economist
Helga Vierich, Principal Social Anthropologist

Senegal

S. C. Gupta, Principal Millet Breeder

Mali

J. F. Scheuring, Principal Cereals Breeder and Team Leader
S. V. R. Shetty, Principal Agronomist (from June)
P. G. Serafini, Principal Agronomist (until April)

Nigeria

S. O. Okiror, Principal Millet Breeder and Team Leader
J. F. MacFarlane, Principal Entomologist (until June)
S. V. R. Shetty, Principal Agronomist (until June)

Kenya
Brhane Gebrekidan, ICRISAT/SAFGRAD Coordinator for Sorghum and Millet, Eastern and Southern Africa

Sudan
R. P. Jain, Principal Millet Breeder

Malawi
K. R. Bock, Principal Groundnut Pathologist and Team Leader
S. N. Nigam, Principal Groundnut Breeder

Mexico
V. Y. Guiragossian, Principal Sorghum Breeder
C. L. Paul, Principal Sorghum Agronomist

Syria
K. B. Singh, Principal Chickpea Breeder
M. V. Reddy, Principal Chickpea Pathologist

SADCC Regional Sorghum and Millet Improvement Project, Zimbabwe
L. R. House, Sorghum Breeder and Project Manager (from April)
E. W. Nunn, Farm Development Specialist (from June)
W. Williams, Administrative Officer (from June)

Pakistan
M. S. Rahman, Principal Chickpea Breeder/Pathologist (from November)

Research Programs

Sorghum

L. R. House, Principal Plant Breeder and Program Leader (until April)
S. Z. Mukuru, Principal Plant Breeder (Acting Program Leader from April)
L. K. Mughogho, Principal Plant Pathologist
J. M. Peacock, Principal Plant Physiologist
K. Leuschner, Principal Cereal Entomologist
Bhola Nath Verma, Plant Breeder (until June)
D. S. Murty, Plant Breeder
B. L. Agrawal, Plant Breeder
Belum V. S. Reddy, Plant Breeder (on leave from January)
N. Seetharama, Plant Physiologist (on sabbatic leave from August)
R. K. Maiti, Plant Physiologist
P. Soman, Plant Physiologist (from December)
Suresh Pande, Plant Pathologist
R. Bandopadhyay, Plant Pathologist
S. L. Taneja, Entomologist
H. C. Sharma, Entomologist
H. D. Patil, Senior Research Associate
S. P. Jaya Kumar, Administrative Officer

Pearl Millet

D. J. Andrews, Principal Plant Breeder and Program Leader (until May)
F. R. Bidinger, Principal Plant Physiologist (Acting Program Leader until September)
S. B. King, Principal Plant Pathologist (Acting Program Leader from September)
J. R. Witcombe, Principal Plant Breeder (from April)
K. K. Lee, Principal Cereals Microbiologist (from August)
K. N. Rai, Plant Breeder
B. S. Talukdar, Plant Breeder
Pheru Singh, Plant Breeder
S. B. Chavan, Plant Breeder
G. Alagarswamy, Plant Physiologist (on sabbatic leave from September)
V. Mahalakshmi, Plant Physiologist
P. Soman, Plant Physiologist (transferred to Sorghum from December)
S. D. Singh, Plant Pathologist
R. P. Thakur, Plant Pathologist
S. P. Wani, Microbiologist
K. R. Krishna, Microbiologist
Nirmala Kumar, Administrative Officer
M. K. O'Neill (International Intern, until August)

Pulses

Y. L. Nene, Principal Plant Pathologist and Program Leader
D. G. Faris, Principal Plant Breeder, Pigeonpea
J. B. Smithson, Principal Plant Breeder, Chickpea (until May)
W. Reed, Principal Entomologist (on sabbatic leave from May)
C. Johansen, Principal Agronomist (from July)
H. A. van Rheenen, Principal Plant Breeder, Chickpea (from October)
J. Arihara, Assistant Physiologist, Pulses (Visiting Scientist, TARC)
O. P. Rupela, Agronomist/Microbiologist
J. V. D. K. Kumar Rao, Agronomist/Microbiologist
D. M. Pawar, Agricultural Officer (Cooperative Trials)
M. D. Gupta, Senior Research Associate (on study leave from November)
K. C. Jain, Plant Breeder, Pigeonpea
K. B. Saxena, Plant Breeder, Pigeonpea
S. C. Gupta, Plant Breeder, Pigeonpea
Harjit Singh, Plant Breeder, Pigeonpea (from May)
Onkar Singh, Plant Breeder, Chickpea
C. L. L. Gowda, Plant Breeder, Chickpea
S. C. Sethi, Plant Breeder, Chickpea
Jagdish Kumar, Plant Breeder, Chickpea (on sabbatic leave from July)
N. P. Saxena, Agronomist/Physiologist
Y. S. Chauhan, Plant Physiologist
S. S. Lateef, Entomologist

S. Sithanantham, Entomologist
S. P. S. Beniwal, Senior Plant Pathologist (until November)
M. P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist (until November)
A. M. Ghanekar, Plant Pathologist (from May)
V. S. Bisht (Research Fellow)
D. R. Dent (International Intern)
I. S. Dundas (International Intern, from November)
S. Dwivedi (Research Fellow, from March)
S. B. Sharma (Research Fellow)

Groundnut

R. W. Gibbons, Principal Plant Breeder and Program Leader (on sabbatic leave until April)
D. McDonald, Principal Plant Pathologist (Acting Program Leader until April)
D. V. R. Reddy, Principal Plant Virologist (on sabbatic leave until April)
J. H. Williams, Principal Plant Physiologist
J. P. Moss, Principal Cytogeneticist (on sabbatic leave from October)
J. A. Wightman, Principal Entomologist (from August)
L. J. Reddy, Plant Breeder
P. Subrahmanyam, Plant Pathologist (on sabbatic leave from April)
A. M. Ghanekar, Plant Virologist (until April)
M. J. Vasudeva Rao, Plant Breeder
V. M. Ramraj, Plant Physiologist
V. K. Mehan, Plant Pathologist
P. T. C. Nambiar, Microbiologist
P. W. Amin, Entomologist
A. K. Singh, Cytogeneticist
D. C. Sastri, Cytogeneticist
S. L. Dwivedi, Plant Breeder
R. C. Nageswar Rao, Plant Physiologist
A. B. Mohammed, Entomologist (until October)
P. Subrahmanyam, Administrative Officer
S. N. Azam Ali (International Intern)
K. M. Dick (International Intern, from December)
M. Dutta (Research Fellow)
H. A. Hobbs (International Intern, from March)
S. Nahdi (Research Fellow, from March)
Rasheedunisa (Research Fellow, until November)

Farming Systems

S. M. Virmani, Principal Agroclimatologist and Program Leader (on sabbatic leave from November)
J. R. Burford, Principal Soil Chemist (Acting Program Leader from November)
R. W. Willey, Principal Agronomist (until August)
C. W. Hong, Principal Soil Scientist (ICRISAT/IFDC)
S. A. El-Swaify, Principal Soil Scientist (until July)
G. E. Thierstein, Principal Agricultural Engineer (on sabbatic leave until December)
T. Takenaga, Principal Agricultural Engineer (ICRISAT/TARC)
J. L. Montieth, Agroclimatologist (Visiting Scientist, July to December)
D. Sharma, Coordinator, On-farm Research
A. B. S. King, Cropping Systems Entomologist (ICRISAT/TDRI, from March)
R. Busch, Principal Soil Scientist (ICRISAT/Justus Leibig University)
M. Wurzer, Principal Assistant Soil Scientist (ICRISAT/University of Hamburg)
A. Schutt, Assistant Engineer, Soil Fertility Unit (ICRISAT/University of Hamburg, from December)
Piara Singh, Soil Scientist
Sardar Singh, Soil Scientist
T. J. Rego, Soil Scientist (on sabbatic leave from October)
K. P. R. Vittal, Soil Scientist
K. L. Sahrawat, Soil Chemist (on sabbatic leave until July)
A. K. S. Huda, Agroclimatologist
M. R. Rao, Agronomist
M. S. Reddy, Agronomist
M. Natarajan, Agronomist
H. Yaoi, Associate Agronomist (ICRISAT/JICA, from September)
R. C. Sachan, Agricultural Engineer
K. L. Srivastava, Agricultural Engineer
R. K. Bansal, Agricultural Engineer
Prabhakar Pathak, Agricultural Engineer
C. S. Pawar, Entomologist
N. K. Awadhwal, Agricultural Engineer/Soil Physicist (from September)
S. K. Sharma, Senior Research Associate
A. A. H. Khan, Senior Research Associate (Engineering)
V. M. Mayande, Senior Research Associate (Engineering)
Surendra Mohan, Senior Administrative Officer
S. Ramachandran, Senior Secretary (until July)
R. T. Hardiman (International Intern)

Economics

M. von Oppen, Principal Economist and Program Leader
R. A. E. Muller, Principal Economist (from June)
T. S. Walker, Principal Economist (ICRISAT/ADC, on sabbatic leave from September)
N. S. Jodha, Senior Economist
R. D. Ghodake, Economist
R. P. Singh, Economist
R. S. Aiyer, Senior Administrative Officer
K. G. Kshirsagar, Senior Research Associate
K. V. Subba Rao, Senior Research Associate
M. J. Bhende, Senior Research Associate
N. V. Narasimhan, Research Fellow (from August)
V. Ballabh, Research Fellow (from January)

Support Programs

Biochemistry

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Umaid Singh, Biochemist
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Santosh Gurtu, Senior Research Associate
M. S. Kherdekar, Senior Research Associate

Electron Microscopy

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P. Remanandan, Botanist
V. Ramanatha Rao, Botanist

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N. Rajamani, Senior Administrative Officer

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B. Diwakar, Senior Training Officer
T. Nagur, Senior Training Officer
A. Prakash Rao, Training Officer (until June)
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Murari Singh, Statistician

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A. R. Das Gupta, Senior Engineer (Communication)
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K. R. C. Bose, Engineer (Civil, from September)
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S. N. Kapoor, Manager (Farm Operations)
S. K. Pal, Senior Plant Protection Officer
K. Ravindranath, Senior Engineer (Farm Machinery)
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