# ICRISAT

Report 1994

## ICRISAT's Mission

Through international research and related activities, and in partnership with national research systems, to contribute to sustainable improvements in the productivity of agriculture in the semi-arid tropics (plus other countries in which ICRISAT's mandate crops have relevance) in ways that enhance nutrition and well-being, especially of low-income people.

# ICRISAT Report 1994

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

1995

**Cover** *A farmer in post-war Rwanda harvesting sorghum grown from seed supplied by ICRISAT through the Seeds of Hope Project. Photograph – S B King.*

# Report from the Chairman and Director General

'ICRISAT Now—Sowing for the Future', published in early 1994, outlined the challenges ICRISAT faces, and described how we were reorganizing ourselves to meet those challenges. In 1995, we can look back with satisfaction on what we have achieved during the past year, and see what these achievements promise for the future.

The Institute has now completed its transition from a hierarchial management system to a matrix organization with research projects as the primary units of management. The new organizational structure is designed to improve teamwork, and facilitate the deployment of multidisciplinary teams to work on specific problems. Once solutions are found, these teams will disband and regroup to attack other problems. In mid 1995 we will review the new organization and management structure, and judge the extent to which the functioning of the Institute has improved. Staff at all levels and from all locations will be involved in this exercise, with a team of management experts visiting each location to gather feedback.

ICRISAT has always prided itself on the cost-effectiveness of its operations, and its ability to deliver research products even under financial strain. The strain was unusually severe in 1994. Funding levels were declining and future prospects were uncertain. We were therefore forced to scale down our operations. We are now able to report that this has been achieved, and without losing the basic vitality built up within ICRISAT over the 22 years since it was founded. The number of staff has fallen by more than 1000 (37%) since 1990. About half this reduction came in 1994, when 550 staff in India left the Institute under a series of voluntary retirement schemes. In addition to this retrenchment, we have also moved to a fixed-term contract mode of employment to improve both staff productivity and management flexibility. New staff are hired on contract terms, and existing staff are being offered incentives to switch to contracts under a scheme that becomes operational in February 1995.

We recognize that these events have put considerable strain on all staff; we now anticipate a period of stability during which our project teams can work efficiently and enthusiastically in even closer collaboration with our partners.

**Research projects** ICRISAT's research portfolio contains a series of global, multidisciplinary projects based on the 92 core research themes of the 1994–98 Medium Term Plan. These research themes have been operationalized in 23 research

projects, of which 22 will be implemented with core funding. While the project on finger millet improvement in eastern Africa had to be dropped, and a potential project on sorghum improvement in Latin America did not reach this stage, we hope to implement this important work using special project funds. In addition, with the exception of the project on genetic resource conservation, whole research activities were dropped from all other projects.

The project formulation process has been described in earlier ICRISAT publications—how research priorities were set, and how the projects relate to the 29 production systems at which ICRISAT's work is targeted. The basic idea of using the project as the unit of research management was to increase flexibility and improve teamwork, while simultaneously ensuring that individual creativity could flourish. Responsibility, financial authority, and most important, accountability, were devolved to project team leaders. Before the new system was put into place, training and orientation courses were held, in which *every* team member participated. This ensured that as we move into the project mode in January 1995, each team functions as a cohesive unit, with a clear understanding of how the new system will work.

Our partners in the national agricultural research systems (NARS) were closely involved at each stage in the planning process; first through informal consultations, and subsequently through formal collaborative planning meetings in all three regions. NARS inputs were vital to the process. Indeed, without such inputs, we could not have developed such a clearly prioritized research agenda that combines a global focus with attention to specific regional concerns. This interaction is continuing, with inputs from our NARS partners on project development and implementation.

During the course of project formulation, we took an inventory of our expertise, technologies at various stages of development, and human and financial resources. We fine-tuned our estimations of future problems—where they would occur, how best they could be tackled, and what aspects could be more effectively addressed by the NARS, whose research capabilities have progressed rapidly. The result of this review is a more focused ICRISAT. We now have the benefit of a detailed analysis of our strengths and weaknesses, and those of our partners, so that we can work together even more effectively to improve life for smallholder farmers in the semi-arid tropics.

**Systemwide Initiatives** Another feature of 1994 was ICRISAT's active involvement in four CGIAR Systemwide Ecoregional Initiatives. Key problems of broad ecoregional significance have been identified, with special emphasis on resource conservation and management. These are being addressed by the combined resources of several CGIAR institutes. ICRISAT has accepted responsibility as Convening Center for the Initiative on Sustainable Natural Resource Management Options to Arrest Land Degradation in the Desert Margins of sub-Saharan Africa (referred to in this report as the Desert Margins Initiative), and as the Facilitator of the Rice-Wheat Consortium for the Indo-Gangetic Plains. Along with the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Institut d'économie rurale (IER) in Mali, ICRISAT will co-convene one of the themes (Optimizing Water Use) within the Systemwide Soil, Water, and Nutrient Management Initiative. It will also be an active participant in the Systemwide Livestock Initiative.

*Involvement with the Systemwide Livestock Initiative will add a new dimension to several ICRISAT projects.*

Target-oriented research on clearly identified problems forms the basis of these Initiatives. In addition, all Initiatives will promote technology exchange through seminars, workshops, publications, and training and institution building to strengthen NARS research capabilities. Follow-up studies will be conducted to monitor technology adoption and impact, and to ensure that our research is properly targeted and responsive to farmers' needs. Perhaps the most positive aspect of this new thrust is the extent of participation. For example, the Desert Margins Initiative involves 8 CGIAR centers, NARS in 6 countries (Botswana, Burkina Faso, Kenya, Mali, Niger, and Uganda), 5 donor agencies, 9 mentor institutions in Australia, Denmark, France, Israel, Netherlands, UK, and USA, plus 7 international and 6 regional organizations. Of

Barbara Adolph

*Every drop counts—SAT farmers must harvest and store precious water if their crops are to survive.*

course, the diversity of participation also results in high transaction costs, which is a matter of considerable concern.

**Other changes** A number of changes, both in administration and in research management, were implemented in 1994. The objective was to decentralize operational and administrative control from the Corporate Office to the Executive Directors in each region. This process of decentralization will continue through 1995, but the benefits, in terms of a more streamlined administration, are already evident.

Financial management has been strengthened, and re-oriented to service the project mode of operation. A new computerized financial accounting system for Institute-wide use was installed in late 1994 at both ICRISAT Asia Center (IAC) and ICRISAT Sahelian Center (ISC). Arthur Anderson and Co was appointed ICRISAT's auditor, replacing A F Ferguson and Co, who had served in this capacity since 1972.

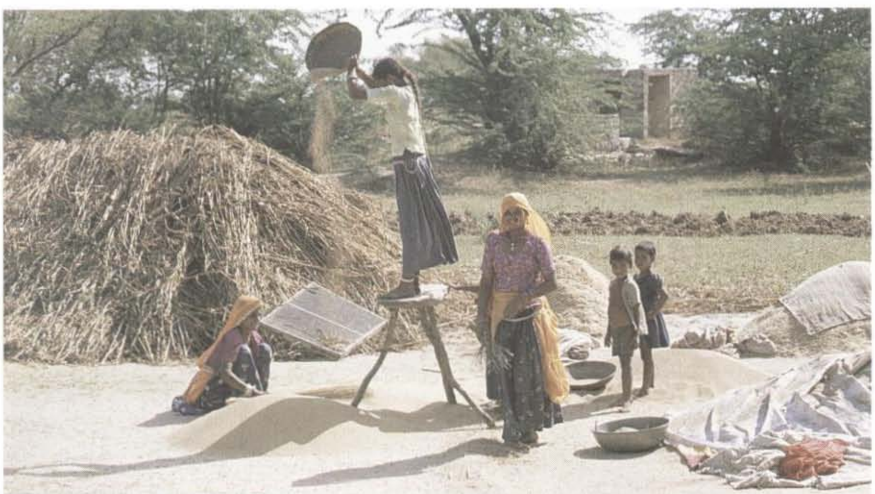
**Spouse employment** Another significant initiative in 1994 was the development and implementation of an employment policy for spouses of internationally recruited staff. Following a consultancy undertaken by an ICRISAT spouse, terms of reference were drawn up for the appointment of International Liaison Persons (ILPs) at major ICRISAT locations, to be recruited from amongst the ICRISAT spouse community.

M M Anders

*ICRISAT works with national programs to help farmers produce food—even from the sand.*

The ILPs' main roles are to identify employment and training opportunities both within and outside ICRISAT, and help match these with spouse aspirations and experience. A Resource and Information Center has been established at IAC to help spouses make the most of local opportunities.

**Reviewing ICRISAT's work** The Governing Board is consciously taking a more active part in the direction of the Institute's work. It recognizes that good science needs stability to flourish, and scientists need time to think. At the same time science benefits from constructive criticism, and donors need independent reassurance that their investment is being used to maximum advantage. In order to respond on both counts, while minimizing disruption to the main work of the Institute, the Governing Board has initiated a series of tightly focused Internally Commissioned External Reviews. These will be a prelude to the External Program Management Review planned for 1996/97. Five priority areas have been identified—a review of the recently revised organization and management structure of the Institute; a review of the Genetic Resources Division and its work; regional reviews of western and central Africa, and of southern and eastern Africa; and a review of ICRISAT's research on soil, water, and nutrient management, which should increase the effectiveness of our participation in the Systemwide Soil, Water, and Nutrient Management Initiative.



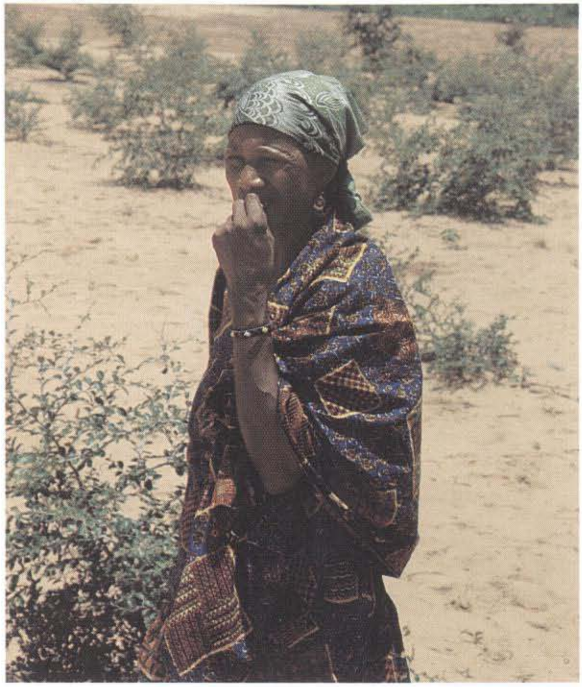
M M Anders

*Winnowing grain is a family affair in Rajasthan; new varieties offer higher yields of both grain and fodder.*

**The future** The CGIAR has been privileged to have a succession of Chairmen who combine broad-based experience in the developing world with a vision for the future in which progress is driven by research and technological advancement. In January 1994, Dr Ismail Serageldin, World Bank Vice President for Environmentally Sustainable Development, took over the Chairmanship of the CGIAR. He arrived during a particularly uncertain period, and responded with a series of initiatives to revitalize donor support and renew the CGIAR system. The changes he initiated are now gathering momentum, and it is testimony to his leadership that within a single year he has succeeded to a considerable extent in changing the environment within which we work.

As we have indicated, ICRISAT has also undergone significant changes to revitalize itself. As with the CGIAR in general, ICRISAT now faces the future with renewed vigor. Challenges persist, but ICRISAT's restructuring enables us to achieve more with less, and to face those challenges with greater confidence.

ICRISAT scientists deal with a particularly fragile set of ecologies. The biological and socioeconomic realities of stressful environments dictate that high yields are not feasible, and therefore 'green revolutions' within the SAT are not expected. But it is reasonable to expect steady progress towards developing improved and sustainable agricultural systems that can help to protect these fragile environments. We will work towards that goal with the confidence that while the goal itself may be some distance away, the road has been laid, and the milestones clearly marked.



*A revitalized ICRISAT will focus even more closely on ways to help farmers in marginal environments.*

**Eric H Roberts**
Chairman, Governing Board

**James G Ryan**
Director General

*This section provides highlights of recent ICRISAT achievements. It is not intended to provide a full historical coverage. Rather, this sample of events and accomplishments is selected to present a digest of ICRISAT's work during 1994. Annual Reports from regional headquarters provide more detailed descriptions of specific achievements.*

*Some of these highlights cover work that has been completed; others cover new work or initiatives. The Institute's research projects focus on specific production systems in Africa, Asia, and Latin America and the Caribbean. These projects and production systems are described in the section on ICRISAT's Research Project Portfolio, beginning on page 61. The abbreviations used for the various projects (PM1, CP3, etc.) and production systems (PS) are listed in the Acronyms section on pages 78 and 79.*

## Putting biotechnology to work

Biotechnology is now the cutting edge of plant science—offering new techniques, new applications, and new opportunities for crop improvement. ICRISAT scientists use a variety of techniques to track genes that determine specific traits (for example, drought tolerance or disease resistance), make crosses between species previously believed to be incompatible, and produce improved genotypes much faster than was possible using traditional methods.

### Gene mapping

One of the most far-reaching applications in recent years is restriction fragment length polymorphism (RFLP) mapping—the use of DNA fragments as genetic markers to follow chromosome segments through segregating generations. The traditional method used to follow genes (more accurately, follow chromosome segments to which the genes are attached) was to actually produce crosses and see how traits (flower color, plant height, etc.) in the progeny relate to those in the two parents. By inference, scientists could deduce how segments from the parental chromosomes recombined and expressed themselves in the progeny. This process is effective, but often logistically complex and time-consuming. Using DNA markers—practically unlimited numbers of markers are available in virtually all plant species—scientists can now directly follow chromosome segments during recombination, and create genetic maps far more quickly and accurately than before. Plant breeders are excited, and with good reason. Rather than selecting for a particular trait (which can be tricky because expression of the trait may depend not only on genetic factors but also on environmental conditions and genotype-environment interactions), they can now select for the presence or absence of molecular markers linked to genes controlling that trait.

### Marking the pearl millet map

In 1990, with funding from the UK Overseas Development Administration (ODA), ICRISAT began a collaborative study with the Cambridge Laboratory in Norwich. The objective was to develop a genetic linkage map for pearl millet using molecular markers. In 1994, the team published the first such map, based on RFLP. Because the map is relatively small (the rice map is more than five times as large), fewer markers are needed to get a fairly accurate picture of the arrangement of genes on the chromosome. Smaller maps have another advantage. RFLP maps are available for only a few crosses. To locate genes in crosses for which no maps are available, scientists transfer a skeleton map from a previously mapped cross; with small maps, fewer markers are needed to transfer the skeleton map to the new cross. (This skeleton map provides a rough framework of gene linkages in the new cross; the details are filled in later by focusing on specific areas of interest and using more markers.)


C T Hash

*The pearl millet genome map is small, but the benefits it offers breeders are considerable.*

The disadvantage of small maps is that they are associated with high 'linkage drag' during backcrossing. When plant breeders try to transfer a desirable gene from one genotype to another by backcrossing, other genes also tag along with the desirable gene. Fortunately, this difficulty can generally be overcome by further generations of backcrossing and/or random mating.

Application of this map to pearl millet improvement is already in progress at ICRISAT Asia Center (IAC), in collaboration with the NARS in India and Niger, and with laboratories in the UK. Genes conferring strain-specific resistance to populations of pearl millet downy mildew from India, Niger, Nigeria, and Senegal have been tagged. Exploratory marker-assisted backcross programs under way at IAC (under project PM2) will transfer some of these genes into elite hybrid seed parents of commercial importance in India, and into CIVT, an improved open-pollinated cultivar widely grown in Niger. Other target traits for ongoing mapping studies include seedling heat tolerance for Production System 1 (PS1) under project PM1, and terminal drought tolerance for PS8 (under PM2).

### Pearl millet haploids

When plant breeders try to improve a particular trait, such as seed size or tillering ability, they usually use a homozygous line—a line in which the trait of interest is genetically 'fixed', with little variation between individual plants. Using conventional methods, it can take several years to develop a homozygous line, particularly in such highly heterozygous, cross-pollinated crops as pearl millet. One solution is to start from haploids—plants that have half the normal number of chromosomes. Standard methods are available to convert haploids to dihaploids (which are homozygous) by doubling the number of chromosomes.

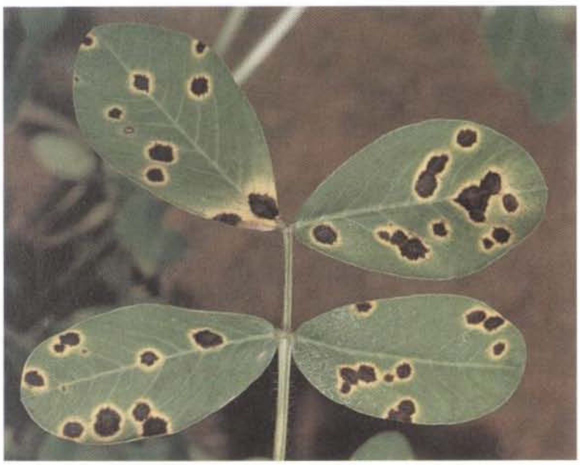
ICRISAT biologists use a two-step method to produce haploid plants. First the anthers are cultured in a suitable tissue culture medium so that a callus (a mass of undifferentiated tissue) is formed. The callus is then transfered to another medium to allow the cells to differentiate and eventually form embryoids, from which haploid plants can be regenerated. Scientists at IAC have successfully managed the first step, inducing callus development in cultured pearl millet microspores, and are now working on step two, regeneration of whole plants from calli.

Androgenesis, or the development of a haploid from a microspore, is influenced by several factors, including temperature, light, and the chemical composition of the culture medium. ICRISAT scientists found that androgenic response is improved if the millet panicles are pre-treated at low temperature (14°C gives good results) for several days before being placed in the medium. Other important findings—incubation in red light is preferable to keeping anthers in the dark; and sugars (especially sucrose) in the culture medium have important effects on androgenesis. Ongoing experiments deal with the effects of various media, hormones, and gelling agents. The results, together with earlier data, will help develop a protocol for the production of haploids from microspores.

### Wide hybridization

Many wild species, over millennia of natural selection, have perfected the art of survival in hostile environments. They could be resistant to diseases and pests, or hardy enough to withstand extreme climates. But they are often of little use to farmers, because they have evolved for survival, not cultivation. Cultivated species, on the other hand, may give high yields, but may also be susceptible to one or more constraints. Landraces fall somewhere in between—low to moderate yields, but good adaptation and resistance.

ICRISAT scientists are trying to combine the best of both worlds—to engineer the resistance in wild species into high-yielding cultivated varieties. Easier said than done; cross-breeding is easy when two species are closely related, but not when they are genetically very different. It is possible to produce hybrids between two distantly related species, under carefully controlled laboratory conditions. But even if fertilization does occur, the embryo may not develop to maturity. One answer is embryo rescue—quite literally, to rescue the embryo after fertilization occurs, and place it in a culture medium that allows it to survive. Despite these difficulties, ICRISAT has achieved some remarkable successes with several of its mandate crops, often in partnership with laboratories in mentor institutions.



*Early leaf spot—hybrids between cultivated groundnut and wild species offer hope of resistance.*

**Groundnut** One of the worst problems that groundnut farmers face is early leaf spot disease, which occurs almost wherever the crop is grown. Economists estimate that successful research on the disease could generate benefits worth over US$ 80 million a year. Unfortunately, very few germplasm lines are resistant. Some wild species do have resistance, but are incompatible with cultivated groundnut (*Arachis hypogaea*). Scientists at IAC worked on two wild species from South America, *Arachis appressipila* and *A. paraguanensis*. After several years of experimentation, they developed suitable hybridization, embryo-rescue, and tissue-culture techniques to obtain hybrids. Some of these hybrids carry the resistance genes, and will be used to develop adapted cultivars.

Very few wild species have so far been used in groundnut improvement, but scientists are hopeful that over the next few years, several more will yield their secrets. A special project on the preservation of wild *Arachis* species is now being planned, with support from the World Bank and the Common Fund for Commodities (CFC), a new donor to the CGIAR. ICRISAT will work together with Centro Nacional de Pesquisa de Recursos Genéticos e Biotechnologia (CENARGEN) in Brazil and the Centro Internacional de Agricultura Tropical (CIAT). The project will also evaluate resistance in wild species, and study ways to use this resistance to combat not just early leaf spot, but also other major groundnut diseases.

**Chickpea** Despite decades of research, ascochyta blight continues to ravage chickpea fields in northern India, Pakistan, and the West Asia and North Africa (WANA) region. Strong resistance to the disease has been found in *Cicer pinnatifidum*, a wild species collected in Turkey and conserved in the ICRISAT genebank. By developing workable embryo-rescue and tissue-culture techniques—hitherto not available for chickpea—IAC scientists have produced hybrids between cultivated chickpea (*Cicer arietinum*) and *C. pinnatifidum*. These hybrid plants are now grown and maintained in vitro. Once scientists find a way to ensure that these hybrids can survive in the soil, they will be crossed with cultivated varieties to develop genotypes that farmers can use.

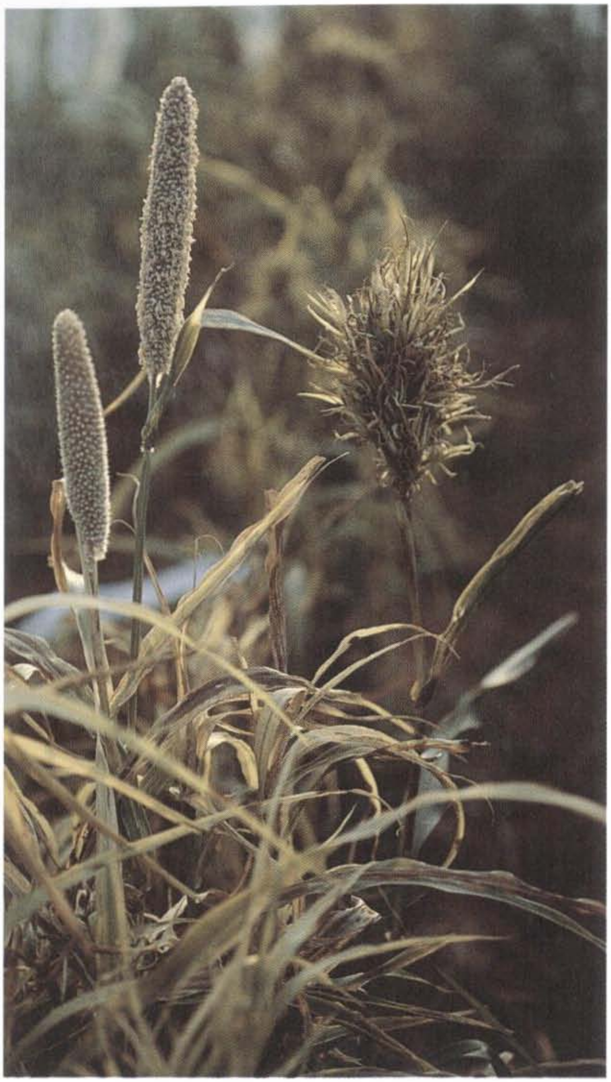
K M Ahmed/Ch Ravinder Reddy

*Wild chickpea species could provide resistance genes against ascochyta blight.*

**Pigeonpea** *Cajanus platycarpus*, a distant relative of cultivated pigeonpea (*C. cajan*), has many desirable characters—extra-early flowering and maturity, annuality, photoperiod-insensitivity, high harvest index, rapid seedling growth, salinity tolerance, and resistance to phytophthora blight and pod borers. Until recently, it was not possible to transfer these characters to cultivated genotypes. But by fine-tuning existing techniques and developing embryo-rescue techniques for pigeonpea, ICRISAT has succeeded in producing the first ever hybrids between *C. platycarpus* and cultivated pigeonpea. Many fertile hybrid plants have now been produced, and used to raise the next generation of hybrids. This population shows a lot of variation, but some plants flower very early and are insensitive to photoperiod. Efforts are in progress to develop a stable hybrid population that can be effectively used in pigeonpea improvement programs.

## Marked for improvement

Postrainy-season sorghum occupies over 5.6 million ha in India, but grows and yields poorly compared to the rainy-season crop. A new ICRISAT initiative is exploring ways to distinguish between rainy-season and postrainy-season genotypes from seed samples, without having to grow the genotypes in the field. Three kinds of molecular markers—protein (isozymes) and DNA markers (RFLP and RAPD, or randomly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*Downy mildew—studies on pathogen isolates are helping to fight pearl millet's biggest enemy.*

amplified polymorphic DNA)—were used to do this. Each of the three types was useful, but RFLP markers appeared to be the most efficient in distinguishing between the two types. By pooling data from the different markers, scientists were able to clearly distinguish between rainy- and postrainy-season sorghums from seed samples—thus avoiding two or three seasons of costly, time-consuming field trials.

Having identified a group of potential postrainy-season genotypes, the next step is to use molecular markers to characterize a larger working collection, and to identify markers to tag plant traits useful for breeding postrainy-season sorghums. These studies involve the National Research Centre for Sorghum in India, and the Crop Biotechnology Center of the Texas A&M University, USA.

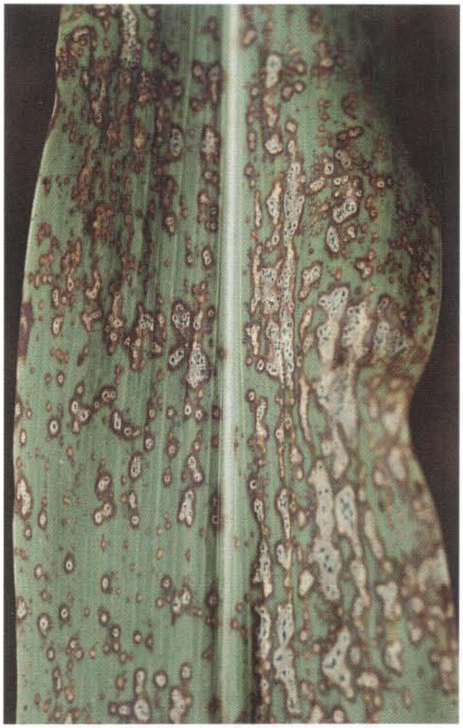
### Pearl millet downy mildew

In large parts of the SAT, food security depends heavily on the pearl millet harvest. Downy mildew is the single most important disease of pearl millet; and economists estimate that successful research could potentially result in extra production worth US$ 118 million a year. Open-pollinated varieties can suffer significant losses, and hybrids are even more vulnerable—several commercial hybrids in India proved so susceptible that they had to be withdrawn from cultivation. ICRISAT pathologists and breeders have made considerable progress in understanding the disease and developing resistant cultivars and improved management practices (see Awards and Distinctions section).

Further success came during 1994, as a result of collaborative work with the National Chemical Laboratory at Pune, India. A genetic variability study on the pearl millet downy mildew pathogen *Sclerospora graminicola* led to the first report on the use of DNA fingerprinting in determining genetic variability among pathogen races. DNA from six host-specific pathotypes was analyzed using oligonucleotide probes (pieces of single-strand DNA that can be detected by various methods). Using a method known as cluster analysis, the six pathotypes were classified into five groups on the basis of genetic similarities. This grouping agreed with earlier results obtained using RAPD markers, thus confirming the existence of host-specific virulence in the pathogen. How does this help? When a new isolate is reported, pathologists subject it to a series of virulence tests to determine how serious it is likely to be, and which hosts are potentially susceptible. This information can now be obtained more quickly and accurately, by using RAPD makers and cluster analysis to compare the new isolate to earlier known isolates. Depending on which 'cluster' the new isolate belongs to, scientists can predict how it will behave, and modify resistance breeding strategies accordingly.

### The answer to anthracnose

Anthracnose is a fungal disease that has been reported from most sorghum-growing areas around the world. Economists estimate that successful anthracnose research could yield benefits of over US$ 66 million a year. A recent, major advance is the use of RAPD markers. Earlier studies provided evidence that the disease pathogen *Colletotrichum graminicola* was highly polymorphic in nature. Several slightly different life-forms exist, an evolutionary defence mechanism to ensure that although environmental conditions may vary, at least part of the pathogen population will survive and multiply.



*Bright colors, big losses—sorghum leaves infected by anthracnose.*

ICRISAT molecular biologists studied pathogen variability in C. *graminicola* isolates collected from 14 locations in India. Of the 60 oligonucleotide primers tested, eight detected polymorphism. That's bad news, because it means that the pathogen is more variable (and therefore more difficult to control) than many others. For example, in downy mildew, 30 primers were tested, but because variability was not so high, only one primer was able to detect polymorphism.

Data from the RAPD markers allows molecular biologists to group isolates in clusters. When coupled with virulence data (some isolates are more virulent than others), the results will help pathologists to better understand the disease, and breeders to develop anthracnose-resistant varieties. Ongoing DNA fingerprinting studies, using highly specific micro- and minisatellites as DNA probes, aim to confirm and characterize variability in the anthracnose pathogen.

### Cytoplasmic male-sterility in pigeonpea

ICRISAT produced the world's first pigeonpea hybrid in 1992, using genic male-sterility, in which sterility is controlled by genes in the cell nucleus. While the hybrid exhibited the classical performance advantages over open-pollinated varieties, it was costly to produce. The reason? In a genic male-sterility system, only half the plants are male-sterile; the remaining plants have to be manually uprooted to ensure that they do not pollinate the plants that will produce hybrid seed. A way around this problem is to develop a cytoplasmic male-sterility (CMS) system, in which sterility is controlled by genes in the cytoplasm that surrounds the cell nucleus. In this system, *every* plant is male-sterile, and pure-breeding male-sterile lines—and from them, hybrids—can be produced cheaply and reliably.

*Using improved male-sterility systems, hybrid pigeonpea seed can be produced quickly and cheaply.*

ICRISAT is working on the development of a CMS system for pigeonpea, and on methods to use molecular markers to classify CMS lines. At the request of the Indian Institute of Pulses Research, the Institute has also convened a working group on male-sterility systems, involving Indian NARS and seed companies. In 1994, two advanced-generation male-sterile progenies based on a cross between cultivated pigeonpea and *Cajanus sericeus* (a wild relative) were found promising in greenhouse tests at IAC. Seeds from these progenies were then sown in experimental plots to see whether the CMS would be effective under field conditions. Pod and seed set were good in the experimental plots, and female fertility was adequately maintained. About 60–70% of plants were male-sterile, compared to the ideal 100% in stable CMS. Further experiments are in progress; and as the percentage of male-steriles improves, so will the prospects of commercial production of cheap hybrid pigeonpea seed.

## Building the biomass

Farmers want their crop plants to grow fast and productively. The scientists' job is to to ensure that nothing hinders growth. To do this it is necessary to study the various processes involved in plant growth, and find ways to measure these processes accurately. ICRISAT scientists use two broad methods to assess growth rate; by the amount of water or by the amount of radiation a plant uses. The former can be calculated by measuring water-use efficiency, or transpiration ratios. Results from all three methodologies and their implications for different crops are reported here.

### Water-use efficiency

Whether a plant is likely to be successful in semi-arid environments depends on how efficiently it uses the limited water available. This efficiency is difficult to measure; crop physiologists earlier measured water-use efficiency (WUE) indirectly, by measuring carbon isotope discrimination Δ. Now they've gone a step further, by using specific leaf area (SLA, the area per unit mass of the leaf) as a surrogate for Δ. SLA is related to Δ, and is easier and much cheaper to measure (Δ analysis of a single plant tissue sample costs US$ 27).

Experiments on various groundnut genotypes grown under irrigated and water-deficient conditions at IAC demonstrated that both Δ and WUE are related to SLA. The lower the SLA (which usually means thick leaves), the higher the Δ and WUE. Working with scientists from the Indian Council of Agricultural Research (ICAR) and the Australian Centre for International Agricultural Research (ACIAR), IAC physiologists have devised a simple selection procedure for WUE that promises to make breeding for drought tolerance quicker and easier.

*Physiology experiments in controlled environments to study how efficiently groundnut crops use water.*

## Transpiration ratios

The transpiration ratio of a plant is a measure of how efficiently it uses water to build up biomass. A high transpiration ratio would be useful in any genotype, and particularly in such crops as pearl millet, which are usually grown in areas where rainfall is low and irrigation is not available. Physiologists trying to improve transpiration ratios have a problem—it is difficult even to measure these ratios accurately. The reason is that only a part of the water supplied to a crop (through precipitation or irrigation) is transpired by the plants; the rest evaporates from the soil surface or is lost in deep drainage.

Scientists at the ICRISAT Sahelian Center (ISC) have successfully tested field and pot methods of measuring pearl millet transpiration ratios (kilograms of biomass produced per kilogram of water transpired). In the field method, irrigation was applied to the lower soil layers through drip irrigation lines buried below the surface. Very little water reached the surface layer, from where it could evaporate.

The effects of genetic differences, management practices, and *Striga* infestation on transpiration ratios are being investigated. In a series of field and pot experiments, transpiration ratios were found to increase both with drought stress and with increased fertilizer application. In the pot study, transpiration ratios decreased with *Striga* infestation; apparently, this ubiquitous weed reduces the amount of biomass that crop plants can produce from a given water supply. Transpiration ratios in the field were higher for the local landrace than for an exotic short-duration variety, suggesting that high transpiration ratios may be an indication of adaptation to arid environments.

Genetic differences in the ability of genotypes to produce biomass under water-deficient conditions in different environments (varying in nutrient availability and biological stress) will be evaluated. The objective of continuing studies under projects PM1 and PM2 is to develop a simple, rapid screening test for pearl millet growth ability under various stresses—information vital to breeders working on drought tolerance.

## Radiation effects

Plants, like babies, grow quickly. But just how quickly? And how does one measure the changes that occur as a crop develops? Crop physiologists can use this information to model plant growth, and then apply the model to improve grain and fodder yields. Such studies are particularly important in SAT environments, where stress factors (e.g., drought or disease) can cause plant growth rates to fluctuate.

The traditional way to measure growth is simple in principle—serial sampling for dissection and measurement of leaf area and shoot, root, and fruit mass—but expensive and time-consuming, especially when a large number of genotypes have to be tested. ICRISAT physiologists have come up with an alternative method for measuring crop growth rates in groundnut that works as well or better, is far cheaper, and requires less labor.

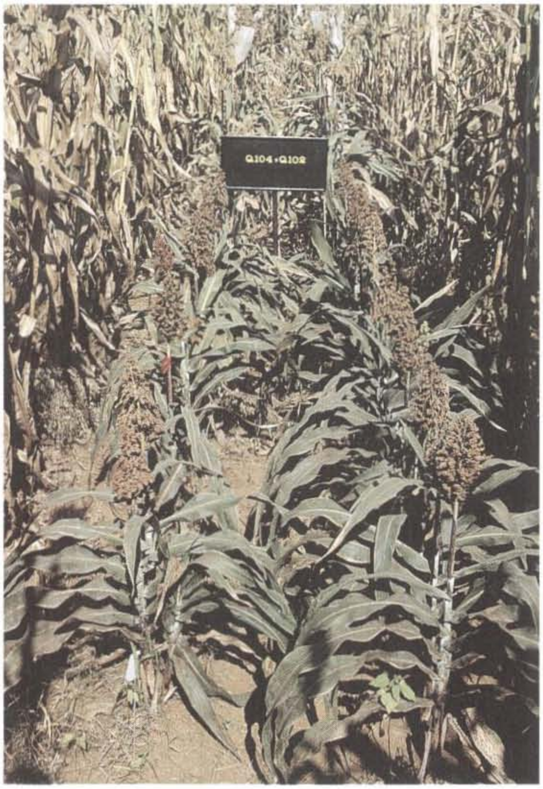
The biomass produced by a plant depends on how much radiation energy it absorbs, and how efficiently it uses this energy to grow. In the new method, the amount of radiation intercepted by the plant is measured. From the radiation-use efficiency of that genotype (which is known), scientists can estimate what proportion of the intercepted radiation is used for biomass production, and thereby calculate progressive changes in biomass. A major advantage of this method is that plants in a standing crop don't have to be uprooted. Yields are measured at harvest, and from the radiation data, physiologists can 'backtrack' to plot the changes that occurred through the growing season.

*New non-destructive methods are now available to measure the rate at which groundnut crops produce biomass from radiation energy.*

Results from this method were compared with data from destructive testing for a variety of genotypes grown under both irrigated and rainfed conditions. The two sets of results matched each other fairly closely. The method is still being perfected—the results can be used in most cases, with two important exceptions. Radiation interception measurements are often inaccurate under drought conditions or during the early growth stages, or for short-statured genotypes. However, there are alternative ways to measure radiation interception under these conditions. Using the new technique, perhaps in combination with some destructive testing, crop scientists can soon expect to gain new insights on plant growth in groundnut—and in the future, perhaps in other crops as well.

## Sorghums stay green

ICRISAT physiologists are trying to find a way to delay senescence in sorghum for as long as possible. The key is the non-senescence or stay-green character, which delays the onset and/or rate of normal plant senescence. This results in delayed or reduced mobilization of proteins from the leaves, and greater accumulation of starch during the later stages of grain filling. Plants that stay green longer seem to provide more nutritious leaf and stem material for cattle feed and other uses, and in addition are probably better equipped to survive end-of-season drought stress. Most stay-green research has been done on temperate sorghum; ICRISAT scientists are studying the physiological expression of the trait and its genetic control in tropical sorghum, in order to develop improved stay-green genotypes for cultivation in the SAT.



*Some sorghums can stay green for longer than others—can they provide better fodder for SAT livestock?*

Green leaf area duration, or GLAD (the cumulative green leaf area that a plant accumulates from flowering to final senescence) can be described in terms of three components—leaf area at flowering, time of onset of senescence, and rate of senescence. Stay-green genotypes (high GLAD) have a favorable expression of at least one component (e.g., a slow rate of senescence) and at least average expression of the other two components.

Genetic analysis provided clues to how these three components are inherited. For two components—leaf area at flowering and rate of senescence—there is complete dominance. In other words, the progeny from a cross has the same level of these traits as its best parent. For time of onset of senescence, the genetic effects are additive—time of senescence in the progeny is somewhere between that in the two parents. As a result, the inheritance of GLAD showed overdominance, i.e., individual hybrids had *higher* GLAD values than their best parent. Breeding for stay-green should therefore be relatively easy—generally because of the overdominance of the trait, and particularly because separate components of GLAD can be manipulated in specific crosses.

Cultivation of stay-green varieties, once they become available, can benefit farmers in several ways. If such plants are indeed more tolerant of terminal drought in the SAT (as they are in temperate climates), farmers reduce the risk of crop failure, even in hard years. Fodder quality will improve, and farmers can get higher market prices for stover. Stay-green work at ICRISAT is continuing under two sorghum projects, SG2 and SG5. The results will benefit farming systems across a very large part of the SAT—PS7, 8, 9, 14, 15, 20, 21, and 22—and also the areas targeted by the Systemwide Livestock Initiative.

## Millet systems in the Sahel

Traditional cropping systems in the Sahelian region (PS13) are millet-based—essentially a continuous millet/cowpea intercrop grown at low plant populations with no chemical fertilizers, and all operations performed manually. ICRISAT agronomists working in collaboration with the NARS have developed improved systems, designed in response to specific constraints in the traditional systems—low productivity and plant populations, losses in productivity caused by nutrient mining as fallow periods are shortened because of demographic pressure, the limiting physical properties of soils in the Sahel, and a shortage of labor for farming operations.

*New systems offer Sahelian farmers better alternatives to growing continuous millet/cowpea intercrops.*

Experiments conducted at ISC between 1986 and 1993 compared fertility, productivity, and labor demand in the new systems with those of traditional practices. The objectives were to quantify the benefits the new systems provided, and to determine whether they were practicable, economically viable, and environmentally compatible. The millet/cowpea intercrop was compared with sole millet, sole cowpea, and millet-cowpea rotations. The new systems received phosphatic fertilizer, and were sown at higher than traditional densities.

Phosphorus application clearly improved yields in both cowpea and millet. Rotating a millet/cowpea intercrop with sole cowpea boosts both productivity and fertility, but it also requires more labor than the continuous millet/cowpea intercrop. Nonetheless, estimates of productive capacity showed that in most years, the new systems use resources more efficiently than the traditional system. The highest yields were obtained when sole millet was rotated with sole cowpea.

These studies were conducted both on-farm and on-station, in collaboration with the Institut national de recherches agronomiques du Niger (INRAN). This work is linked to ISP1. Follow-up studies will use intertemporal productivity measures to determine the sustainability of new cropping systems, and will dovetail with research conducted under the Desert Margins Initiative.

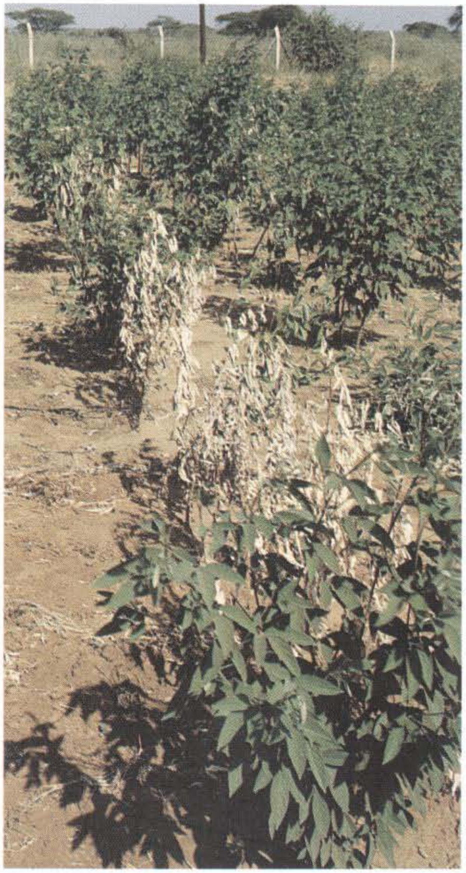
## Weeding out *Striga*

The parasitic weed *Striga hermonthica* is endemic to semi-arid tropical Africa, where it attacks cultivated cereals (sorghum, millet, maize, upland rice), sugarcane, and wild grasses. *Striga* reduces yields by about 25% on average, but sometimes wipes out the entire crop in localized areas. This can have major repurcussions on the sustainability of cereal farming systems—about 44 million ha of land in Africa is threatened, and annual loss of revenue from infestations in maize, sorghum, and pearl millet is estimated at US$ 2.9 billion. Recent surveys in Benin, Cameroon, Gambia, Ghana, Nigeria, and Togo found *Striga* in about half the cultivated fields. Subsistence farmers are particularly affected, because they cannot afford the existing control methods.

Striga *flowers are beautiful, but the weed must be uprooted and burned before it ruins the crop.*

*Striga* research at ICRISAT is designed to provide subsistence farmers with sustainable, adoptable, low-cost technologies. For the past 4 years, a NARS/ICRISAT team has been evaluating the effectiveness of local cultural practices in controlling *Striga* in farmers' fields near ISC. Rotating groundnut with a pearl millet/cowpea intercrop considerably reduces the number of *Striga* seeds in the soil; consequently, fewer *Striga* plants emerge during the cropping season. Weeding is also effective, but in large parts of Africa, labor is in short supply; farmers must trade off the advantages of weeding against the cost and effort involved. Agronomy experiments at ISC have shown that for pearl millet, a single additional weeding during the flowering stage, at which millet plants are most vulnerable to competition, was as effective as weeding or hand-pulling regularly every 2 weeks. For the higher-rainfall zone in southern Niger, they suggest another solution that greatly reduced *Striga* infestation while maintaining yield at acceptable levels—use photosensitive pearl millet varieties, and sow them late at high seeding rates.

ICRISAT is now helping to establish a collaborative network for *Striga* management, in partnership with NARS, the Universities of Hohenheim, Türbingen, and Giessen, and specialized institutions in Canada, Germany, Italy, UK, and USA. For example, joint research on the use of molecular markers to identify resistance genes, and on fungal antagonists that could help control *Striga*, is being funded by Bundesministerium für Wirtschaftliche und Entwicklung Zusammenarbeit (BMZ)/Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).



S B King

*Growing pigeonpeas in the new wilt sick plot at Kiboko highlights locational differences in wilt disease expression.*

## The war against wilt

The wilt caused by *Fusarium udum* is the most important pigeonpea disease in eastern and southern Africa. NARS/ICRISAT teams working in several countries in the region have made considerable progress towards controlling the disease. But breeders' efforts to develop resistant cultivars are often frustrated by the unusually varied nature of the pathogen. Different races occur at different locations, and a genotype that is resistant at one location may be susceptible at another. For example, ICP 9145, which is resistant in India and Malawi, suffered less than 15% infection at Katumani (Kenya), but over 70% infection at Kiboko, just 100 km away. In the short-duration lines, which are relatively wilt-free in India, 70% of plants were infected at Kiboko.

One solution is to develop more test sites, with different environmental conditions and different pathogen populations. ICRISAT and the Kenya Agricultural Research Institute (KARI) initiated the development of a new wilt-sick plot at Kiboko, during the 1992/93 season, and expanded the plot in 1993/94. There are now two sick plots in Kenya, and a third will be developed in Uganda in 1995. These activities are being funded by the African Development Bank.

Multilocational wilt screening will be intensified in the coming seasons, with NARS from several countries working together to provide potentially wilt-resistant genotypes, develop and manage test sites, and conduct advanced trials of promising material. There will be inputs from India as well, in terms of results from a wilt nursery run jointly by ICAR and ICRISAT since 1978. Eventually, this work will result in the development of resistant genotypes, more insights into the pathogen itself, and information on the adaptation of pigeonpea throughout southern and eastern Africa.

## Getting to grips with groundnut viruses

Viruses are harder to fight than most other pathogens. The traditional method was to identify a naturally resistant genotype and progressively improve its resistance by selection. Today, virologists work differently. They create a transgenic plant by isolating a viral gene and inserting it into the plant. The transgenic plant reacts in roughly the same way as the human body does when confronted with a disease pathogen. It produces a defence reaction as a result of interaction between the viral gene and the plant genes. When the plant is attacked by a similar virus under natural conditions, the defence reaction is strong enough to ensure that the plant remains disease-free. Essentially, virologists have created a resistant plant. Breeders can then take over—working if necessary from that *one* resistant plant—improving resistance or transferring it to other well-adapted cultivars using conventional breeding methods.

But finding resistance is only step two. Even step one—diagnosing which virus(es) is responsible for causing a particular disease—presents formidable difficulties. Virus detection and characterization are high on ICRISAT's list of priorities, and the results are beginning to show. The major groundnut viruses occurring in the Asia-Pacific region and in some parts of Africa have now been characterized, and serological methods developed for their detection. These viruses include peanut bud necrosis (PBNV), Indian (IPCV) and West African (PCV) peanut clump, peanut mottle (PMV), peanut stripe (PStV), and groundnut rosette viruses. Genome sequencing of two important viruses (PBNV and IPCV) has been largely completed, as a result of collaboration between ICRISAT and several mentor institutions (the Samuel Roberts Noble Foundation, the Universities of Florida and Georgia, the Scottish Crop Research Institute, and the Queensland Department of Primary Industries). The PMV and PStV genomes have been sequenced by researchers elsewhere. Building on these studies, IAC virologists have identified viral genes that will be used to develop transgenic plants, and to develop nucleic acid-based probes for virus detection.


*Genome sequencing of the peanut bud necrosis virus—a vital step towards protecting groundnut crops.*

A multidisciplinary research team is now developing integrated control methods against virus diseases. This work is continuing under projects GN1, GN2, GN3, and CP2, and the potential benefits are enormous —over US$ 240 million a year in groundnut alone. The eventual objective is to develop not only resistant genotypes, but also environmentally friendly, sustainable management practices to control groundnut and chickpea viruses. The results will benefit smallholder farmers throughout the SAT, especially those in irrigated, high-input systems (PS5, 9, 10, and 11), where virus problems are particularly serious.

## Indexing rust spores

Until the late 1960s, groundnut rust, caused by a fungus called *Puccinia arachidis*, was confined mainly to Central and South America. Today it occurs in almost all groundnut-growing regions, and often reduces yields by 50% or more. Agricultural research could potentially generate benefits worth over US$ 240 million a year. After recent outbreaks in Asia and Africa, disease management efforts—mainly through the use of host-plant resistance—were redoubled. A number of partially resistant genotypes have been developed; they are still affected by rust, but the disease develops much more slowly, and the crop is harvested before rust damage becomes too severe. However, before resistance sources can successfully be put to work, more information is required on the components of resistance.

*As crop losses mount, scientists intensify the search for rust-resistant groundnuts.*

Rust resistance is measured in terms of five components—infection frequency, incubation period, lesion diameter, percentage of leaf area damaged, and sporulation index. IAC pathologists studied these components in 143 rust-resistant genotypes, and found that all five components were significantly correlated with each other and with mean field rust scores. So if one component is favorable in a particular genotype, the other components are likely to be favorable as well, allowing breeders to select for any one component when breeding for resistance.

Seventeen of the screened genotypes had low sporulation indices (1.3–2.5 on a 1–5 scale) and long incubation periods (17.1–21 days), indicating that they could at some stage be used for resistance breeding. Studies will continue under projects GN1 and GN2, to identify genotypes with a combination of resistance components, and use these genotypes to breed for stable, durable rust resistance.

## Garlic to the rescue

Ergot is a major constraint to sorghum production in large parts of Asia and Africa. The disease is particularly nasty; developing grains are transformed into sclerotia and contaminated with toxic alkaloids. Total yield loss is not uncommon; in India, farmers who grow seed are the worst sufferers. Several research institutions have conducted screening trials to identify resistant genotypes. However, it was difficult to compare results from different trials, because standard inoculation methods for field testing had yet to be established.

M M Anders

*Garlic has antifungal properties that may prevent the ergot pathogen from infecting sorghum.*

ICRISAT pathologists working in India have now standardized inoculation methods for field testing—when plants should be inoculated, what inoculum concentrations to use, which weather conditions will ensure that the disease develops quickly, and so on. As these methods are adopted more widely, multilocational trials can be planned with greater confidence, and potentially resistant genotypes identified with more certainty.

Another study suggested a possible way to control ergot infection—garlic. Ergot was successfully and consistently controlled in field and greenhouse tests by spraying garlic extract (14–16% in water) on sorghum panicles when the first stigmas began to emerge. The next step will be to identify the active ingredient in garlic. One likely candidate is allicin, an organosulfur compound present in garlic. Allicin apparently has antifungal properties, as indicated by experiments on other diseases; and further studies are planned to examine whether it is in fact effective against ergot, and if so, how best it can be used.

## Getting rid of grain mold

Sorghum grain mold, caused by a complex of several fungi, causes substantial yield losses worldwide; successful research on the disease could lead to benefits of over US$ 120 million a year. Sources of resistance were available in red-grained sorghums, but until recently, not in white-grained varieties. In 1994, ICRISAT pathologists identified several white-grained genotypes with very high resistance levels. About 60 selections from these lines have shown consistently high, combined resistance to three grain mold fungi (*Fusarium moniliforme*, *F. pallidoroseum*, and *Curvularia lunata*) for 2 years running, both in the field and in laboratory tests on threshed grain. Evaluation of these genotypes (under the SG2 project) will now move on-farm, to fields in Maharashtra, India. And if the resistance continues to hold, ICRISAT teams will begin incorporating grain mold resistance into adapted varieties for use in farmers' fields.

*Flag-bearers in the fight to overcome grain mold—the first white sorghums with high resistance levels.*

## Legume pests – the fight continues

*Helicoverpa armigera* is the most important pest of pigeonpea and chickpea, and causes worldwide yield losses of more than US$ 600 million a year in these two crops. As Indian farmers began getting higher prices for their produce, they began

*Pest-specific viruses could reduce the* Helicoverpa *threat.*

using more insecticides to protect their pigeonpea and chickpea crops. A collaborative project that brings together several institutions—NRI, ICRISAT, and ICAR—has clearly demonstrated widespread resistance in *Helicoverpa* to a wide range of insecticides (particularly pyrethroids) commonly used in India. Less easy to quantify is the environmental degradation that results from insecticide over-use, and the effects of accumulating these chemicals in the human food chain.

ICRISAT is working with Indian NARS and nongovernmental organizations (NGOs) to develop pest management strategies to minimize dependence on insecticides. On-farm research in India during 1994 focused on evaluating pest-tolerant germplasm, biological insecticides, and community action approaches to manage *Helicoverpa* in pigeonpea and chickpea production systems. Farmer-managed trials in their own fields provided a realistic evaluation of prospective pest management technology. Pigeonpea farmers have participated in the evaluation and selection of pest- and disease-resistant cultivars, and have also compared the efficacy of NPV (a nuclear polyhedrosis virus specific to *H. armigera*) with that of conventional insecticides. Chickpea farmers are testing NPV and a neem-based insecticide (now being commercially produced), in combination with pest- and disease-resistant cultivars.

*Farmers learn quickly when the IPM message is conveyed through folk theater.*

Another major pest is *Spodoptera litura*, the tobacco armyworm, which causes serious losses in postrainy-season groundnut. ICRISAT's IPM technology is successfully being used against *Spodoptera* by an increasing number of farmers in coastal Andhra Pradesh. Extension work is being done in collaboration with Krishi Vigyan Kendras (research and extension centers) and NGOs. Folk theater has proved to be a particularly effective medium. A troupe of semi-professional performers preaches IPM through *pallesuddulu*, a traditional form of folk theater that includes songs and dances, with lyrics in the local idiom and tailored to local conditions, using a script prepared with help from an ICRISAT entomologist.

## Surveying sorghum bugs

B D Hall

*An open and shut case—because lax sorghum panicles shelter fewer pests, they suffer less infestation than compact ones.*

Nigeria produces about 4.1 million t of sorghum each year, and could produce far more, but for insect pests. For example, in western Africa the sorghum head bug *Eurystylus immaculatus* alone causes losses worth over US$ 60 million each year. Despite the seriousness of the problem, little quantitative information is available on the pest's occurrence and distribution, and the damage it causes. In 1993, ICRISAT and NARS entomologists began a series on-farm surveys to find some of the answers.

The first survey covered 73 locations in seven states in Nigeria (PS13–16). *Eurystylus* was found at two-thirds of the locations, and on just over half of the 390 panicles sampled. At 11 locations, *every* panicle in the sample was infested. Surveys in late 1994 covered nearly 100 farms in nine states and the Federal Capital Territory of Abuja in Nigeria, two provinces in southeastern Niger, and northern Benin. They confirmed that the insect is widely distributed in all three countries. Head bugs were found on over 80% of the farms sampled in Nigeria, and *all* farms in Niger. Just over half the 572 sorghum panicles examined were infested.

Infestation and damage were most severe on semi-compact to compact panicles, probably because such panicles shelter pests more effectively from predators. This finding is important for sorghum varietal development. Traditional landraces are gradually being replaced by high-yielding, compact-headed durra types, many of which are likely to be susceptible to pests. Breeding new sorghum cultivars will therefore involve a trade-off between yield and pest resistance, unless scientists can engineer acceptable resistance levels into otherwise excellent genotypes.

## Minding the miners

The millet head miner (*Heliocheilus albipunctella*) is a key pest in western and central Africa, where it causes annual losses estimated at US$ 116 million; PS13 and 14 are the worst affected production systems. Laboratory studies at ISC have yielded considerable new information on head miner biology, which will help develop more effective pest management methods. It is now possible to mass-rear the pest throughout the year, and thereby cut down the time required for entomology experiments. Progress in developing a screening technique is very encouraging. The most susceptible stage of the millet panicle has been determined, and ICRISAT entomologists are very close to determining just how many larvae are needed to cause various levels (up to 70%) of damage to susceptible cultivars. Determining these 'threshold' levels is the first step towards effective pest management. Once farmers know what level of damage they can expect (judging by how many larvae are found on the plants in a field), they can decide how best to control the infestation. A damage rating scale is being developed for use in farm surveys; and correlations between damage ratings and actual grain losses show that this rating scale is sufficiently reliable for wider use.

O Youm

*Head miner moths lay their eggs between developing grains in pearl millet panicles.*

## Beating the borers

The millet stem borer (*Coniesta ignefusalis*) is a major pest of millet in sub-Saharan Africa, where it causes crop losses estimated at US$ 91 million per year. The pest is most serious in PS13–15. Pheromone technology has proved to be highly effective in monitoring the borer, as reported last year in ICRISAT Now, and initial studies show that control is likely to be achieved. Pheromones can be used not just to monitor the pest but also to reduce populations. Many insects find potential mates by tracking the odor of pheromones to their source. In what is aptly known as the confusion technique, pheromones are dispersed over a field through rubber septa, disrupting mating. In 1993, ICRISAT entomologists were able to reduce mating to *one-tenth* of normal levels by using this technique. This technology is already being used in some

*Granaries provide safe havens for millet stem borers. Pheromone trapping can reduce the amount of damage they cause to crops in neighboring fields.*

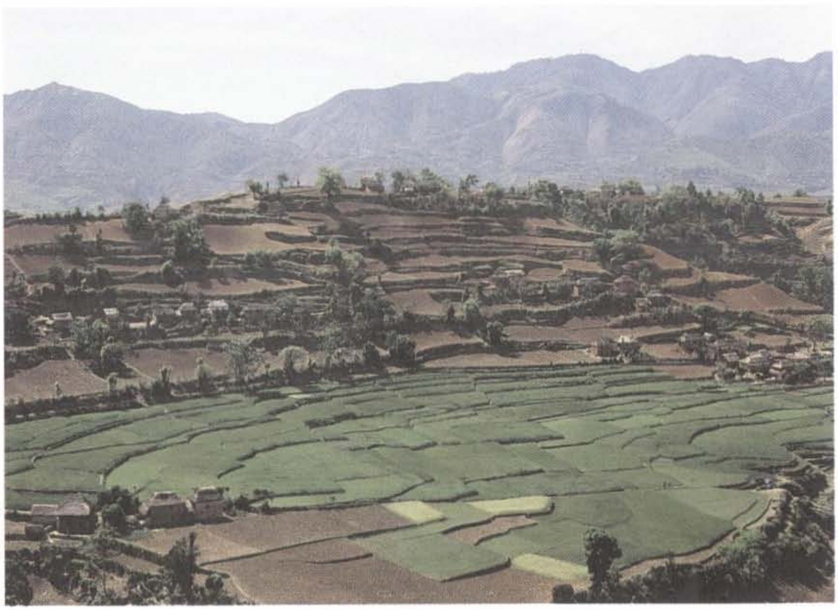
farmers' fields. Research is in progress in collaboration with the NRI, UK, to develop longer-lasting rubber septa that farmers can use to control the pest more effectively.

Mass-trapping using pheromones was tried in Niger in 1994, in collaboration with farmers, in areas of high crop-residue usage. The effectiveness of these traps was particularly striking in the vicinity of fences (built of millet stems) and granaries, both of which are likely to harbor stem borers. Pheromone-treated plots had appreciably less infestation and fewer deadhearts than untreated plots. Further research is continuing, in PM1 and PM2, on the effectiveness and cost/benefit implications of mass trapping. Regional monitoring has been initiated, and results indicate that inexpensive, locally made pheromone-baited traps are efficient and well-adapted to local conditions. It is hoped that by 1997 pheromone-baited traps will be used on a large scale, particularly in areas where the stem borer is endemic.

## Sources of growth

The ECON2 project studies trends in the production, trade, and utilization of ICRISAT mandate crops, and the policy environment (pricing, subsidies, market liberalization, etc.) that shapes these trends. ICRISAT economists made two presentations at the Vision 2020 Workshop organized by the International Food Policy Research Institute (IFPRI) in late 1994. These presentations focused on trends in production, supply, and demand for the major food crops in the semi-arid regions of Asia and Africa. Data on historical trends in key agricultural, socio-demographic, and environmental variables were analyzed, and then extrapolated to obtain projections for food supply and demand to the year 2020, and identify the policy interventions required to ensure food security and growth in agricultural production.

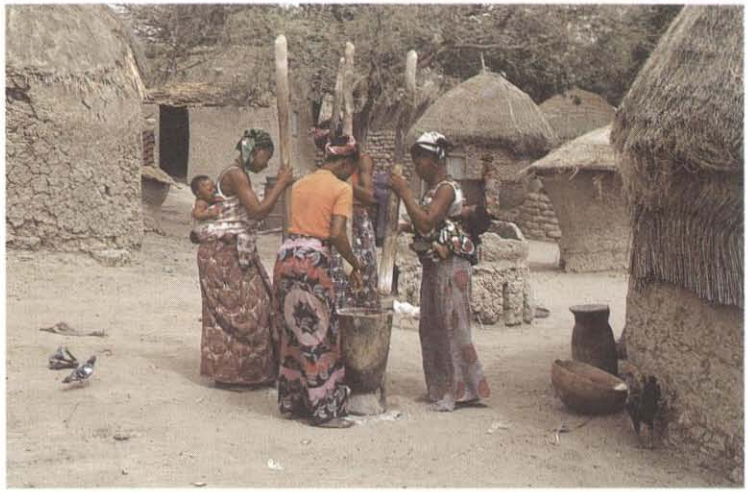
**Asia** Two agroecological zones were considered—the arid and semi-arid tropics (AEZ1, corresponding to PS4 to 9) and the arid and semi-arid sub-tropics (AEZ5, corresponding to PS1, 2, and 3). Together, AEZ1 and AEZ5 cover much of India, all of Pakistan, a small part of Thailand, and about 15% of China. Between 1960 and 1988, productivity increased sharply as farmers began adopting new, high-yielding varieties and using more irrigation and fertilizer. Cereal production shot up, particularly in Pakistan and northern India. However, growth rates are leveling off, and projections indicate that in 2020, AEZ1 will be deficient in cereals and oilseeds, though it will probably generate a surplus in pulses. AEZ5, on the other hand, will probably maintain or sizably increase its surpluses of cereals and milk (although there will be some deficit in pulses and oils).


T G Kelley

*Terraced farmland in central Nepal. Without more skillful resource management, the future could bring severe food shortages.*

Intensification of agriculture has already led to soil erosion, soil salinity, waterlogging, and falling water tables. Because resources are limited, and increasingly at risk through degradation, new sources of growth based on more efficient use of existing inputs must be found through technology development—particularly improved crop management. Further analysis will be carried out in 1995 under the ECON2 project.

**Africa** AEZ1 covers 12.5 million $km^2$ in parts of 26 countries in the warm, arid, and semi-arid tropics of sub-Saharan Africa. The region faces a formidable suite of problems—rapid population growth (409 million people in 1993, projected to increase to 870 million by 2020), widespread poverty, erratic rainfall and frequent drought, environmental degradation, low agricultural productivity, poorly defined land ownership and user rights, and civil strife in some areas.



*Urban consumers prefer rice and wheat, but traditional coarse grains such as millet are still the staple diet in villages.*

Projections for the future indicate that at an urban growth rate of 6.4% per year, urban populations in AEZ1 will grow by 120 million by the year 2020. This will accelerate the trend (already evident) of a consumer shift in urban centers from coarse grain to livestock products and imported rice and wheat. By the year 2020, AEZ1 will face an estimated 65.7 million t deficit in cereals, which must be met by increasing imports or increasing domestic production. Roughly 37 million t of this deficit will be faced in western Africa. Significant increases in cultivated area are unlikely; the solution lies in a combination of technological innovation (in varietal development and resource management), policy and institutional reform (to encourage investment in agriculture) with a greater emphasis on research and extension, and improved support services (roads, seed multiplication and distribution networks, storage facilities).

## Sorghum – the future in India

In India approximately 3 million ha of rainy-season sorghum and 1 million ha of postrainy-season sorghum have been replaced by other crops during the last 25 years. Other factors apart, consumers are simply eating less sorghum than before, not because of a shortage of sorghum, but because incomes are rising, and food preferences are changing. The 'relative area' of rainy-season sorghum (i.e., its share of gross cropped area) has declined significantly in about 60% of the major sorghum-growing districts, with production becoming concentrated in the state of

Maharashtra. Area losses are primarily in Madhya Pradesh, Andhra Pradesh, Karnataka, and Gujarat, across a wide range of soil and rainfall conditions (PS4, 6, 7, 8, and 9). Expansion of irrigation, low producer prices, and lagging productivity have all made rainy-season sorghum less attractive to farmers; the single biggest factor is price movements in favor of competing crops. However, the crop has maintained or improved its competitiveness in about 40% of the districts—generally areas with either low irrigation growth rates or high sorghum yields.

Postrainy-season sorghum area has declined mainly in Andhra Pradesh, Tamil Nadu, and eastern Maharashtra; areas with relatively high rainfall (above 750 mm) in PS5 and 9. The crop has maintained or increased its relative area over a large arid region on the western Deccan Plateau (primarily southern Maharashtra and northern Karnataka, PS8).

What are the implications of these trends? Without large improvements in productivity, rainy-season sorghum is likely to continue to be replaced by other crops, particularly in favorable environments with assured rainfall or irrigation. Cultivar development and crop management research for such environments should aim to close yield gaps and increase yield potential sufficiently to make rainy-season sorghum competitive with higher-valued crops. If improved, high-yielding grain sorghums (as opposed to dual-purpose varieties) continue to be developed and adopted, production will increase and prices will fall. Farmers could respond to the expected growth in domestic and international demand for sorghum grain, and sorghum could potentially replace maize in starch manufacture, poultry and dairy feed, and as raw material for breweries. In less favorable environments (low and erratic rainfall), the decline in rainy-season sorghum is likely to continue—researchers would be better off focusing on more favorable environments, where sorghum has the best chance of competing successfully with other crops.

*New varieties can help farmers tap expanding markets for sorghum grain.*

Postrainy-season sorghum, in contrast, is likely to remain competitive in low-rainfall, poorly endowed areas. Research should focus on developing drought-tolerant, pest-resistant, dual-purpose cultivars that give moderate yields but require few inputs under rainfed conditions. Another research priority should be to assess postrainy-season sorghum competitiveness under moderate input levels, with and without irrigation.

## Chickpea in competition

*Researchers have found ways to dramatically improve chickpea productivity, but adoption of new technologies has been poor.*

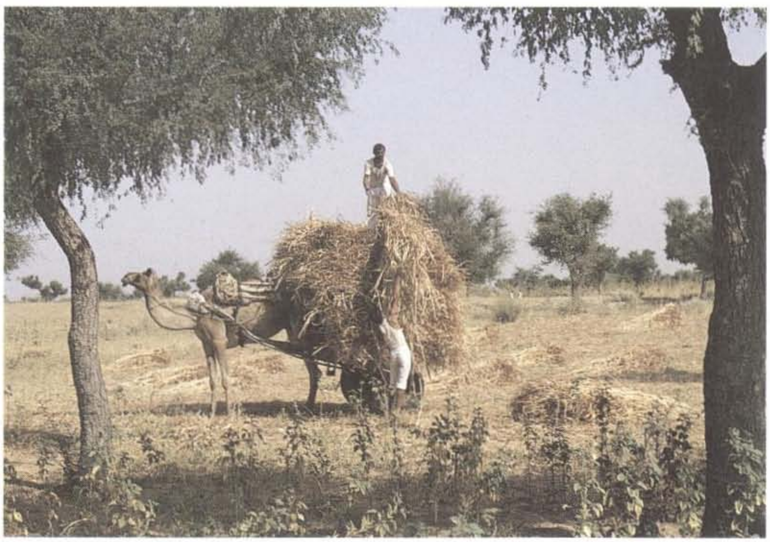
India is the world's largest producer of chickpea, with 65% of the world production. However, productivity has grown slowly, area has declined, and production has remained stagnant during the last 20 years, particularly in the traditional growing areas in PS2 and 3 in northern India. The decline in northern India is likely to continue as chickpea is replaced by more profitable, irrigated postrainy-season crops (wheat and rape/mustard). At the same time, however, chickpea's competitiveness has improved in central and southern India (PS4, 7, and 9), where a combination of yield increases and higher prices has led to a 40% increase in cropped area—nearly 1 million ha—during the last 20 years.

Per capita availability of chickpea in India has fallen by nearly one-third since 1973, essentially because populations have grown while production has not. Chickpea is by far the most important pulse crop in the country, so it is imperative to increase production (and thereby reduce prices) in order to improve nutrition levels and avoid the necessity for large-scale imports. To do this, scientists will have to focus specifically on the major constraints in two areas—ascochyta blight and botrytis gray mold in the relatively productive dryland areas in northern India, and drought, fusarium wilt, and root rot disease in the drier, more marginal areas of peninsular India.

Another priority is identification of the constraints to technology adoption in these two areas. Technology is available that can *double* yields in many areas, but adoption has been poor. Is it because the new technologies are too complex, or because inputs are unavailable, or simply due to poor extension? Once scientists know the answers, they will be better placed to help farmers improve chickpea performance in India.

## Straw, grain, or both?

What role do straw yield and quality considerations play in farmers' decisions on cultivar adoption in pearl millet? ICRISAT socioeconomists surveyed farm households in four villages in the arid environment of western Rajasthan (PS1) to try and find the answers. The survey provided information on several aspects—the relative importance of grain versus straw yield, the perceived risks associated with the use of new cultivars under variable climatic conditions, and farmers' preferences for straw quality characteristics. The conclusions? Improved cultivars were not adopted primarily because of their poor grain yield in years of low rainfall, though poor straw yield under low-rainfall conditions was also important. Even where improved hybrids have found moderate acceptance, a significant number of farmers 're-use' hybrid seed in subsequent years. Farmers are aware of the yield loss associated with the use of second- and third-generation seed. However, they believe that the risk of grain and straw yield loss during low-rainfall years is lower with $F_2$ and $F_3$ generation hybrids than with $F_1$ hybrids. The former are also more acceptable in terms of grain and straw quality.



M M Anders

*Farmers in Rajasthan must use every bit of their pearl millet crop to feed families and livestock.*

These results are particularly pertinent in the light of farmers' perceptions about the likelihood of drought or poor rainfall. When rainfall is poor, farmers are generally concerned more about straw than grain yield; their dependence on crop residues increases since alternative sources of fodder are not readily available. If new pearl millet cultivars are expected to replace the traditional ones, breeders must select genotypes that give acceptable grain and straw yields even when rainfall is poor.

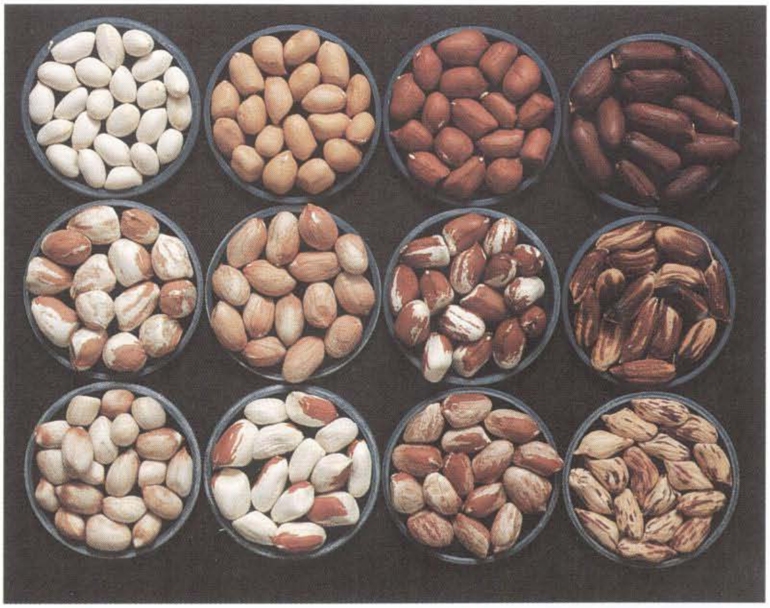
## Producing for Namibian preferences

A collaborative study, undertaken at the request of the Namibian NARS, has provided new insights to pearl millet farming. ICRISAT socioeconomists surveyed 320 smallholder farmers across 16 communities in northern Namibia (PS19), to identify the main constraints to the expansion of pearl millet production and trade, and find solutions. The region currently imports nearly two-thirds of its pearl millet requirements, and market institutions have developed primarily to import and sell grain, mainly maize. Yet, according to recent surveys, 77% of households in the Ovambo region and almost 95% of households in Kavango prefer the taste of pearl millet; they buy maize because it is cheaper.

The investigation outlined a difficult policy choice—reliance on cheap imported grain to hold down consumer prices, versus protection of the domestic grain market to benefit grain producers. In contrast to common perceptions, the grain markets work reasonably efficiently. But most farmers operate extensive, low-input production systems to offset the risks of drought, and yields average less than 250 kg $ha^{-1}$. If Namibian farmers are to compete with cheap imports, productivity must increase. This in turn requires intensification of the production system. On-going technology generation activities under PM1 and ISP1 offer the prospects for such intensification.

## Genetic resources

ICRISAT holds the world germplasm collections of several crops—sorghum, pearl millet, finger millet, foxtail, barnyard, proso, little, and kodo millets (the 'minor' millets), chickpea, pigeonpea, and groundnut. During the year, over 4000 germplasm samples (820 of sorghum, 1897 of pearl millet, 229 chickpea, 287 pigeonpea, 600 groundnut, and 353 minor millets) were added to the collection. The ICRISAT



*The ICRISAT genebank's groundnut collection displays a startling range of variation in seed color.*

genebank now holds 113,002 accessions from 128 countries. NARS/ICRISAT teams conducted germplasm collection missions in different parts of the SAT, looking for little-known landraces and wild relatives of cultivated crops, some of which could hold the key to resistance to specific diseases or pests, or to adaptation to specific environments. As a result of these missions, in 1994 the genebank acquired 160 samples of postrainy-season sorghum and 106 of short-duration chickpea from India, 87 chickpea samples from Tanzania, and 67 samples of wild *Arachis* belonging to 26 taxa (representing six of the nine sections in *Arachis*) from Brazil. Support for ICRISAT's efforts in this area has been further strengthened by a special project on 'Preservation of wild *Arachis* species' funded by the Common Fund for Commodities (CFC) and the World Bank.

*Before seeds leave IAC on their way to genebanks, breeders, or farmers, the Plant Quarantine Unit ensures that they are healthy and will not spread pests or diseases around the world. The millionth consignment left IAC in March 1994.*

Efforts to establish duplicate germplasm conservation centers are continuing: 1500 accessions of sorghum and 500 of minor millets were transferred to the SADC Plant Genetic Resources Centre, Zambia. One thousand accessions of sorghum and 500 of pigeonpea were supplied to the Kenya National Genebank, KARI, and 400 pigeonpea accessions to the National Bureau of Plant Genetic Resources, ICAR, India.

## Drought-tolerant chickpea

Drought is a major constraint to rainfed chickpea production in both the SAT and the West Asia and North Africa (WANA) region. More than 90% of the world's chickpea is rainfed, and 8.7 million ha suffer drought to at least some degree, incurring yield losses ranging from 20% to 50%. Economists estimate that drought research could generate benefits worth US$ 525 million a year. But before drought improvement work can begin, two important prerequisites must be met—drought-resistant parents must be identified, and field screening methods devised for use on research stations.

After screening more than 1500 germplasm accessions and over 150 advanced breeding lines, ICRISAT scientists identified a few drought-resistant genotypes, most notably ICC 4958, a germplasm accession with unusually long roots. Seven environments covering a range of drought severity levels were created at IAC, using different soil types and irrigation levels. Screening techniques developed earlier were then used to characterize drought responses in different genotypes subjected to controlled drought treatments.

Two independent approaches were used for chickpea improvement—conventional breeding (selecting for yield and yield components under natural and/or simulated drought conditions) and ideotype breeding (where the objective was to develop plants with large root systems, which can extract more soil moisture). Both approaches were successful. Yield-based selection identified genotypes that gave acceptable rainfed yields, but were sensitive to drought. The genotypes with large root systems were less sensitive to drought, and produced yields similar to those of the yield-based selections.

The ICRISAT team was able to considerably improve drought resistance in chickpea by using ICC 4958 as a drought-resistant parent. In 1994, elite genotypes were evaluated for drought resistance in the seven 'drought environments'. These genotypes are being further tested at IAC during the 1994/95 crop season in a range of soil moisture environments created using line-source sprinkler irrigation, and in large-scale (90 $m^2$) field plots. The next phase will be to combine drought resistance with high rainfed yield, and to improve resistance to soilborne diseases (fusarium wilt and root rots).

This work—essentially strategic research—is being undertaken under the drought subproject in CP1. Applied research is being done with NARS collaboration in South Asia, with potential impact over a very large area—projects CP1 (PS7–9), CP2 (PS1–4), and CP3 (PS12, spring-sown chickpea in WANA).

*Line-source irrigation can provide a range of soil moisture environments to test drought resistance in chickpea genotypes.*

## Vital traces

Micronutrient deficiencies are common in the sandy, acidic soils of Sahelian West Africa. Although data on the subject are scanty, boron (Bo) and molybdenum (Mo) are believed to be the major deficiencies. Molybdenum availability decreases in acidic soils, and this could have serious consequences—for example, Mo levels in Sahelian soils are insufficient to allow effective symbiotic nitrogen fixation by legumes.

Research undertaken for the last 3 years on the acid sandy soils in the Sudanian zone at Bengou, Niger, has shown that legumes (cowpea and groundnut) and pearl millet respond very strongly to the application of Mo. Field research on Mo is continuing in PS13 and 14, in collaboration with the University of Hohenheim.

The quantity of Mo required is not large—about 200 g $ha^{-1}$ is sufficient. But the fertilizers available in the region, apart from being expensive, do not contain Mo. ICRISAT scientists are working on a possible alternative. Molybdenum is applied to small plots where cowpea and groundnut are grown. The idea is that seed produced by plants that received high levels of Mo fertilizers will contain sufficiently high Mo levels for it to be grown by farmers *without* the need for additional Mo.

## Waste not, want not

Crop yields in the West African Sahel are low, mainly because the soils are fragile and low in fertility. Rather than relying solely on mineral fertilizers (which are expensive and can cause long-term problems if overused), farmers can use organic nutrients from crop residues and manure. Plowing in crop residues helps recycle nutrients, particularly phosphorus and potassium. Residues can provide several other benefits too—protection against wind and water erosion, loosening of the upper soil layers, creation of a favorable environment for soil microbes, and a reduction in soil surface temperature and soil resistance. Crop residue management is critical throughout the Sahel, and particularly in PS13, 14, and 15, where millet is grown season after season, depleting organic matter levels in the soil, and increasing acidity.

M V K Sivakumar

*Sandstorms can devastate pearl millet crops; residues left on the soil surface could help minimize the damage.*

It isn't easy to recommend a standard package for residue use, because the benefits depend on local conditions (rainfall, wind speed, soil type, and temperature). For example, in nutrient-deficient soils, residues would be most effective if they were plowed in. If high temperature is the most serious problem, farmers would be better off leaving part of the residues on the surface. Fodder for livestock is another factor. Fodder shortages are common in the Sahel; and using crop residues to improve fertility may not work if the rains fail—it may be less risky to remove all residues from the field and feed them to livestock.

A multidisciplinary team at ISC is now studying the agronomic and socioeconomic factors that govern crop residue use. In a series of on-farm experiments in a village in southern Niger, they found that the amount of crop residue left in the field depended on how much stover had been harvested; and that this in turn depended on how much fertilizer had been used (the use of single superphosphate fertilizers increased yields nearly four-fold). But unless the millet harvest provides enough fodder for their livestock, farmers will not use crop residues to improve soil fertility.

NARS/ICRISAT fertility management trials, including crop residue treatments, are in progress at Farako Bâ and Kouaré (Burkina Faso), and Tara and Sadoré (Niger). These trials will continue at three on-farm sites in 1995 under the ISP1 and ISP2 projects, and the results are expected to provide clearer answers on how crop residues can be used to improve productivity and sustainability in the Sahel.

## Watershed studies in Ethiopia

In 1994, the Joint Vertisol Project (initiated in 1986 and currently supported by the Government of the Netherlands) entered a new phase, with a project on resource management for crop and livestock production in the Ethiopian highlands. As in the earlier phases (results were reported in the ICRISAT Report 1992), several institutions are involved—the Institute of Agricultural Research (IAR), the Alemaya University of Agriculture (AUA), the International Livestock Research Institute (ILRI), and ICRISAT. An important feature of this new phase is the watershed-based disposal system for excess rainwater, to improve drainage and simultaneously reduce soil erosion and gully formation.

Farmers know that good drainage is important; it reduces waterlogging, and if runoff water is collected and stored, it can later be used for supplemental irrigation, providing substantial benefits at relatively low cost. ICRISAT engineers set about monitoring and quantifying runoff, as part of the Joint Vertisol Project. A broad-crested V-notched weir was constructed in a 60-ha watershed at Ginchi, located on a gentle slope (1.5–3%) at an altitude of about 2200 m in the Ethiopian highlands. The watershed contained wheat, teff (*Eragrostis teff*, an important cereal crop in the region), and fallow fields.

Runoff hydrographs were recorded daily during the rainy season, using an automatic stage level recorder. Early in the season, rainwater seeped into the dry, deeply cracked clay soil, and runoff was relatively low. But as the rains continued, the soil profile gradually became saturated; the clay soil swelled, the deep cracks closed. Infiltration was drastically reduced, and with continuing heavy rainfall, total runoff and peak runoff rates increased—on 12 September, 2 weeks before the rains stopped, ICRISAT scientists recorded the highest peak runoff rate of the season, 2.44 $m^3$ per second, or about 2.3 million US gallons per hour. The cumulative runoff depth during the period was 219 mm, equivalent to 45% of the cumulative rainfall. Rainfall was 40% above average; in drier years runoff on clay soils is a somewhat smaller proportion of total precipitation, but still represents a substantial amount of water that can be stored and used after the rain stops. The scope of this work will be expanded in 1995, to include studies on water harvesting, with support from the Australian Centre for International Agricultural Research (ACIAR).

## Soil structures and systems

The major physical constraint to crop production in most SAT Alfisols is their structural instability, which leads to excessive runoff and soil erosion. In 1988 ICRISAT initiated a study in collaboration with the Queensland Department of Primary Industries (QDPI), on the response of these soil processes to modification of soil structure. Various cropping systems were compared in sole and mixed perennial systems of pigeonpea, *Cenchrus ciliaris*, and *Stylosanthes hamata*. The study also examined how yield changes when tillage depth varies, or soil amendments (rice straw and farmyard manure) are added.

Results from 1989 to date indicate that surface residues enhance water infiltration, reducing runoff that might otherwise be lost to crops. Crops grown on tilled, straw-covered plots had 25–30% more water available than did the control plots (untilled, with no amendments). More water, higher yields—when rice straw was added to zero-tilled plots, sorghum grain yields went up by one-third, and stover yields by nearly 40%. Farmyard manure was somewhat less effective than straw, but still increased water availability by 20% over the control plots.

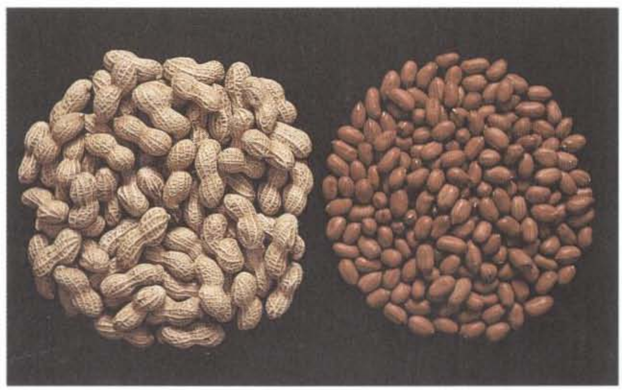
The performance of mixed systems was equally impressive. Runoff was slashed to a mere 4% of the control value over a period of 4 years in a perennial system (pigeonpea + *Cenchrus ciliaris* + *Stylosanthes hamata*), but increased to 50% of the control within 3 years after annual cropping was reintroduced. So how do farmers benefit? Soil structure is often a problem in Alfisols; this study provides a possible solution—rotate annual crops with perennials. The perennial systems improve soil structure, provide both grain and fodder, and improve fertility, thus stabilizing yields of the annual crop that follows the perennials.

Clearly, soil structure management can help stabilize yields in dryland farming. This experiment set out to quantify the benefits of surface residues, deliberately using high levels of straw and farmyard manure as a first step. Follow-up studies under ISP2 will examine sustainability issues in PS9; among other aspects, to see how well the technology performs at input levels that smallholder farmers can afford.

## A package deal for groundnut

A better life for smallholder farmers? Good science isn't enough; it must be backed by good extension work. It is difficult for a single institution to do both; ICRISAT follows the collaborative approach, sharing resources and expertise with other institutions to achieve a common goal. A good example is Malawi, where the national program, the United Nations Children's Fund (UNICEF), and ICRISAT are working together on a package deal for CG 7, a variety that could be a major success story for groundnut in Africa.

CG 7 is a high-yielding confectionery type with a high degree of uniformity in seed size and shape, and a longer shelf life than any cultivar previously released in Malawi. Since 1983/84, it has been evaluated by NARS/ICRISAT teams in 70 trials in five countries, and has shown remarkable stability across environments—a major plus for widespread adoption. CG 7 has been released in Malawi and Zambia (as MGV 4), and has been approved for pre-release multiplication in Swaziland.



*CG 7, a confectionery groundnut with uniform pods and seeds, could earn export dollars for Malawi.*

Variety development is one thing, adoption is another. Adoption is governed by a number of factors—straightforward ones like cost and availability of technology, and more complex factors such as the social and cultural milieu, and compatibility of the new technology with traditional farming practices. ICRISAT-Malawi NARS teams interviewed farmers in the major groundnut areas, gathering information that could help improve the adoption of CG 7. Two problems stood out—inadequate extension and lack of seed. In response to these problems, ICRISAT and the NARS introduced a new scheme during the 1993/94 cropping season, involving over 300 women farmers (most groundnut farmers in Malawi are women). The objective was to deliver affordable, high-quality CG 7 seed to farmers, and simultaneously improve awareness of this variety by establishing on-farm demonstration/evaluation plots. Each farmer in the scheme was given 1 kg of seed. She could retain whatever she harvested, but had to return 1 kg of seed, which would then be distributed to other farmers.

L J Reddy

*Groundnut farmers in Malawi are delighted with new high-yielding varieties; but seed shortages are still common.*

This scheme has several advantages over earlier methods. Because farmers need not buy seed, many more are likely to participate. Farmers who would have used inferior seed, or not sown groundnut at all, now have the chance to evaluate the new cultivar in their own fields. And the 300 kg required to start off the 'seed chain' will have significant multiplier effects. The scheme will be extended to cover progressively larger areas; and as seed availability improves, so will appreciation of the advantages of using improved cultivars.

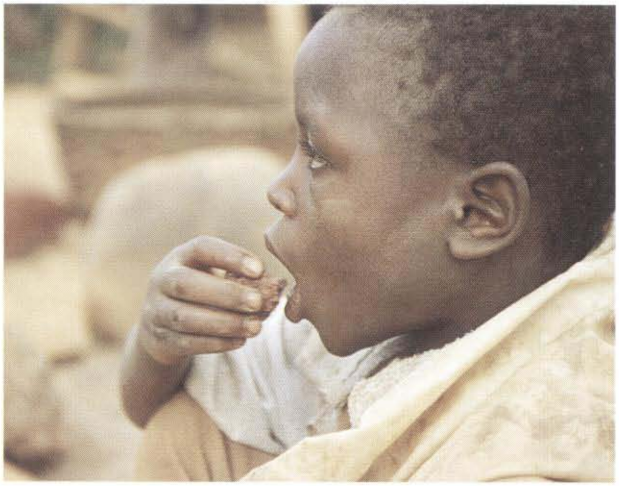
Collaboration with UNICEF focused on another problem—malnutrition. The SADC/ICRISAT Groundnut Project joined hands with UNICEF and the Malawi national program to work on the Child Survival and Development Project in Nkhata Bay district in northern Malawi. The objectives were to reduce child mortality by improving nutrition, and also increase cash incomes of smallholder farmers (until recently, groundnut provided 25% of *all* smallholder cash income in Malawi).

In the 1992/93 season, improved groundnut seed of two cultivars (CG 7 and JL 24, an Indian variety introduced by ICRISAT) was distributed to 100 farmers, the majority of whom were women. In 1993/94, this number had increased to 300. In the first season, seed was provided cheap and on credit, but on a cost-recovery basis; and recovery was almost 100%. In the second season recovery was in kind—farmers had to return as much seed as they had received. As in the seed multiplication scheme described above, farmers grew the improved seed alongside the local cultivar, so that they could make their own comparisons. Technical support was available from NARS research staff, and fields were monitored regularly by ICRISAT and NARS scientists to assess cultivar performance and gather feedback from farmers. Response has been excellent, and the benefits in terms of larger groundnut area, higher yields, better nutrition, and higher incomes will become apparent in the next few years.

## Seeds of Hope

In 1992 we reported ICRISAT's efforts to combat the drought in southern Africa. The emergency seed production project was very successful. Now, the lessons learned are helping to deal with yet another crisis—the civil war in Rwanda.

As the disturbances grew more serious, it became clear that plant genetic resources lost from deserted fields would have to be replaced, and destroyed genebanks rebuilt; and that farmers would need seed when they returned to their fields. But as we reported in 'ICRISAT Now', Rwanda has special needs—temperatures are low in the highland areas, and unless sorghum varieties are adapted to low temperatures, they will produce little or no grain. ICRISAT was strategically placed to contribute, as a result of its work in the highlands of eastern Africa and Latin America.



*Sustenance for a nation rebuilding after war.*

ICRISAT is involved with seven other CGIAR Centers and five donors in the 'Seeds of Hope' project coordinated by CIAT. The purpose of the project is to re-introduce germplasm into Rwanda after the civil war so that Rwandan farmers can start growing their own food again. ICRISAT's genebank contains 256 sorghum landraces collected in Rwanda, and these lines are being multiplied in anticipation of future needs. NARS from Burundi, Kenya, Tanzania, Uganda, and Zaire are also closely involved in seed multiplication, providing facilities and technical support. Work began in June 1994, long before the civil war had ceased. A brochure in English and French was produced to help NGOs involved with seed production and distribution, emphasizing the

R Bandyopadhyay

*Rwanda's red-grained sorghum landraces face genetic erosion; genebanks can provide replacements.*

*Cold-tolerant sorghum—Seeds of Hope for Rwandan farmers.*

need to use seed of genotypes specifically adapted to Rwandan conditions. ICRISAT staff based in Nairobi are actively involved with the effort. An impressive amount of seed of both beans and sorghum has been distributed to farmers through the project. NGOs such as World Vision and CARE International have developed effective distribution networks within Rwanda, ensuring that the Seeds of Hope reach the farmers who most need them.

## Living at the edge

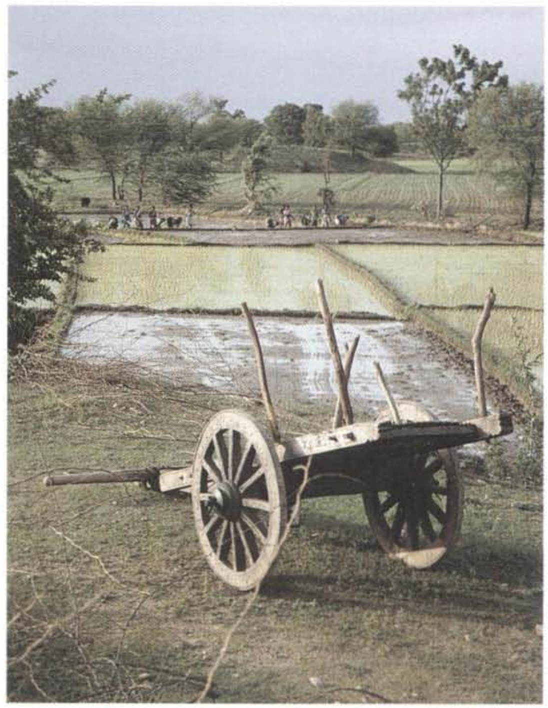
Farmers in the desert margins of sub-Saharan Africa work in a harsh environment; yields are usually low and total crop failure is not uncommon. A new ecoregional research initiative launched by the CGIAR in 1994 has the potential to contribute to a better future. ICRISAT is the Convening Center for a research consortium entitled Sustainable Natural Resource Management Options to Arrest Land Degradation in the Desert Margins of sub-Saharan Africa, which involves seven countries in the region—Botswana, Burkina Faso, Kenya, Mali, Niger, Senegal, and Uganda. Research under this Initiative will aim to improve food security and help alleviate poverty by arresting land degradation. In the first phase, multidisciplinary teams will study land degradation processes and the factors (including agricultural policies) that influence them. Subsequent work will build on these results to improve natural resource management, foster the domestication of tree species, and formulate drought management strategies.

A workshop in Nairobi in January 1995 brought together institutions from diverse backgrounds—8 CGIAR and associated centers, 7 international organizations and specialized agencies, 6 regional organizations, 6 NARS, 8 national environment departments, 4 NGOs, 9 mentor and research institutions, and 5 donor organizations. A framework for action has been developed, clearly specifying the role of each partner in the Initiative.

## Rice-Wheat Consortium

Farming systems in the Indo-Gangetic plains are largely based on rice (grown in the rainy season) and wheat (postrainy winter season). The rice-wheat system occupies 12 million ha in Bangladesh, India, Nepal, and Pakistan, and another 10 million ha in China. Productivity is high, particularly in the Indo-Gangetic plains. However, after remarkable increases during the Green Revolution in the 1960s, 1970s, and early 1980s, yields are now leveling off or even declining; what is now at issue is the sustainability of these rice-wheat systems. Several factors have contributed to this trend, including land degradation, a gradual reduction in soil fertility, and increasing pest and disease problems.

ICRISAT is the Facilitator for the Rice-Wheat Consortium for the Indo-Gangetic Plains, an ecoregional initiative that was launched in response to these problems. The Initiative involves NARS from Bangladesh, China, India, Nepal, and Pakistan working together with five international agricultural research centers (IARCs). There will be additional support from other national programs and several international groups including IBSRAM, IFDC, CIP, and Cornell University. The Initiative is designed to underpin a NARS/IARC alliance to improve the sustainability of rice-wheat systems in the Indo-Gangetic plains. Research strategies were formulated at a meeting in Islamabad in April 1994. Six projects will be initiated, to study productivity trends, crop establishment, soil fertility issues, water management, the ecological consequences of intensive rice-wheat farming, and policy options to enhance sustainable resource management.



Barbara Adolph

*Food security in Asia depends on the health of rice-wheat cropping systems.*

## Technology exchange

For ICRISAT's research to be effective, it is imperative that two-way communication channels operate efficiently between ICRISAT researchers, their collaborators throughout the SAT and elsewhere, farmers, and other intended beneficiaries of ICRISAT's work. To this end ICRISAT is active in established networks, sponsors and organizes conferences and workshops, is a significant publisher, operates training programs at several locations in Asia and Africa, offers fellowships to research students, provides global bibliographic information services, and runs regular Field Days for visitors.

### Networks

Networks are established to improve interaction amongst NARS, and between NARS and research collaborators (including ICRISAT), and thus improve the effectiveness of collaborative projects. Regional consultative meetings, workshops, and technical working groups organized through networks help to identify needs and research opportunities, and assess comparative advantages in specific research areas. ICRISAT is active in the Réseau ouest et centre africain de recherche sur le mil (ROCAFREMI) and the West and Central African Sorghum Research Network (WCASRN); and lends support to the coordinating units for both networks. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) is considering a NARS/ICRISAT proposal to establish a new sorghum and millet network for that region. And in response to members' requests, ICRISAT directly coordinates the Cereals and Legumes Asia Network (CLAN).


G V Ranga Rao

*An ICRISAT scientist works with Vietnamese colleagues during a CLAN working group visit.*

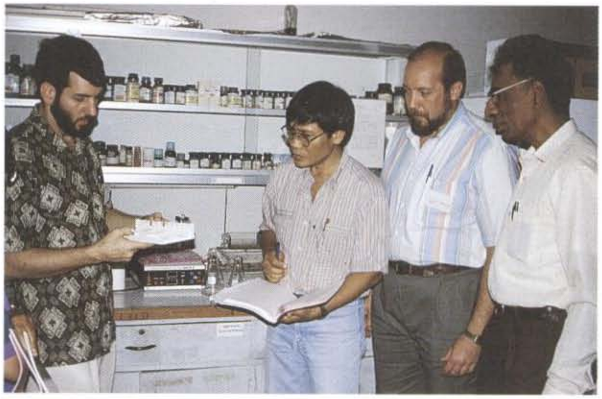
### Extending the frontiers of cooperation

**South Africa** During 1994, for the first time, South African delegates attended two ICRISAT-sponsored workshops to share their knowledge with their colleagues from the Southern African Development Community (SADC). The first was a workshop on sustainable groundnut production for southern and eastern Africa held in Swaziland in July; and the second, a meeting on drought-tolerant crops for southern Africa held at Gaborone, Botswana, in September.

This latter meeting was also attended by delegates from ROCAFREMI and WCASRN, who travelled from western Africa to share their experiences in running cereals networks with the representatives of 10 SADC countries. Their presentations generated considerable interest, as did those of the South African delegates.

Shortly after the Botswana meeting South Africa formally joined SADC. This is very welcome news for ICRISAT and for the future of agricultural research in the region. South Africa's unique geographic and demographic character will make significant contributions to the growing pool of knowledge in southern Africa, and ICRISAT looks forward to collaborative work for the benefit of farmers in the region.

**China** In July 1994 ICRISAT signed a Memorandum of Understanding with China. This signing coincided with a CLAN Working Group Meeting on bacterial wilt of groundnut that involved not only a 3-week training course on the disease, but also a workshop that brought together 39 participants from Australia, China, Indonesia, Malaysia, Thailand, Vietnam, UK, FAO, and ICRISAT. The resulting proceedings contained abstracts in Chinese—the first ICRISAT proceedings to carry that language—made possible through the collaboration of groundnut scientists in China. Training course participants also contributed to another ICRISAT first. During their laboratory work they used a draft laboratory manual and made comments on its practicality and usefulness. These comments helped ICRISAT scientists to revise and publish the manuscript as the first in a new ICRISAT series of technical manuals, designed to pass on practical knowledge of technologies developed at ICRISAT in collaboration with NARS and mentor institutions.



D V R Reddy

*Participants at a CLAN training course in China use equipment provided by ODA, and a draft laboratory manual developed by ICRISAT to diagnose bacterial wilt of groundnut.*

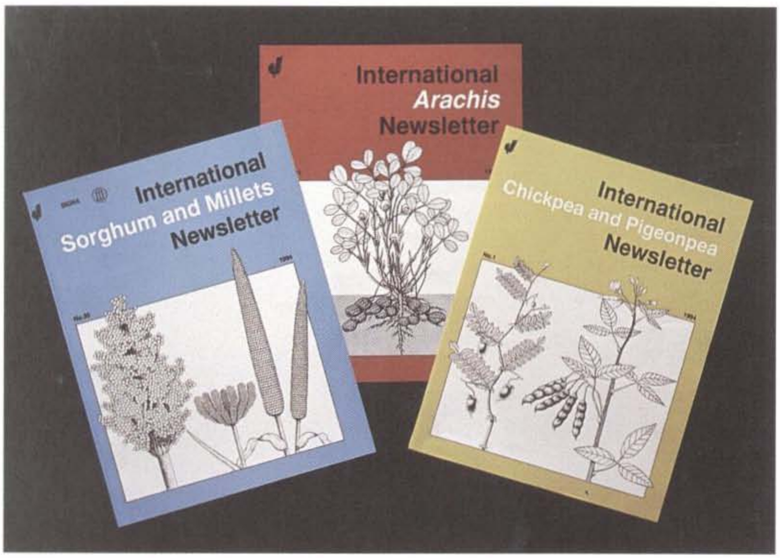
## NARS meetings

ICRISAT cannot work in isolation. To develop new projects and to make sure our research efforts are directed where they are most required, we need feedback and collaboration. During 1994 consultative meetings were held with scientists and senior administrators from the NARS. These meetings involved 10 countries in western and central Africa, and 6 in Asia; similar meetings with representatives of southern and eastern African countries will be held in 1995.

These discussions on ICRISAT's Medium Term Plan and its portfolio of research projects have enabled us to develop projects that will be timely and collaborative, and are designed to produce results that can be rapidly adopted by NARS and farmers throughout the SAT.

### Publishing

ICRISAT continues to be a significant publisher of workshop proceedings, information and research bulletins, newsletters, and other scientific literature. The Institute also continues to generate material to maintain public awareness of the value of its work. As part of this effort, in 1994 we produced a series of six posters in English and French, for distribution to collaborators and extension agencies throughout the SAT; these posters have become very popular, and continue to be in high demand.



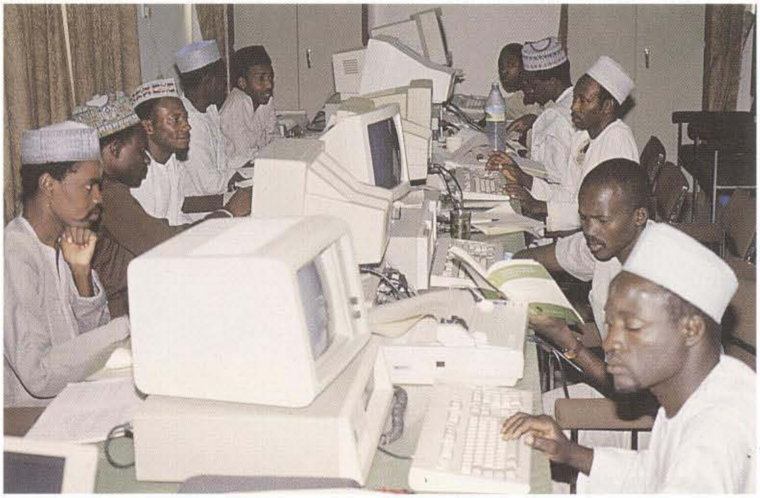

*International newsletters help scientists and extension staff worldwide to share ideas and learn from each other.*

In addition to publishing on paper, ICRISAT is evaluating a number of electronic publishing options. A microcomputer-based expert advisory and diagnostic system for groundnut crop protection reached an advanced stage of development during 1994. In April, researchers and extension staff from the Indian NARS attended a meeting at IAC, where the system was demonstrated; feedback obtained during that meeting has been used to fine-tune both the system's user interface and the information detail it holds.

### Training

The focus of ICRISAT's training programs has changed to reflect the rapid growth in NARS research and training capabilities. ICRISAT now concentrates on providing specialist courses for NARS scientists on such specific topics as disease screening methods, biotechnology, and statistics. These courses are occasionally developed in partnership with mentor institutions in other countries. ICRISAT is also working with other CGIAR Centers to plan and implement coordinated training programs in Africa.

Following a major review of training activities in 1994, an Institute-wide training agenda was delineated as comprising such specialist courses, some in-service training, post-graduate professional training in thesis research, and technical study programs. In addition, courses on 'training the trainers' will be offered to NARS, and more opportunities will be provided for NARS scientists to work as Visiting Scholars with ICRISAT research project teams. Project teams will also involve internationally recruited postgraduate Research Fellows and Visiting Scientists. A program of in-country training courses will be developed in collaboration with NARS and donor agencies, targeting the identified needs of ICRISAT's collaborators.



R Tabo

*ISC staff and equipment went to Nigeria in November 1994 to provide this training course on statistics and computing.*

## Bibliographic information services

Demand for the Selective Dissemination of Information (SDI) service based on the Semi-Arid Tropical Crops Information Service (SATCRIS) bibliographic database continues to grow.

An innovation during 1994 was the publication on diskette of a bibliographic database covering all published material authored by past and present ICRISAT staff. The diskettes contain over 2500 full citations covering journal articles, conference papers, all ICRISAT publications, and theses resulting from work done at ICRISAT. The 'package' also contains software to enable the database to be easily and conveniently searched under a variety of headings. Over 200 copies have been distributed to NARS collaborators and libraries across the SAT, and the feedback is encouraging.

## Field Days

Effective research needs a proper focus, and scientists need to interact with farmers to ensure that their research helps to solve real problems in farmers' fields. One way to achieve this is through field days. New technologies (improved varieties, better management practices) are on display, and farmers provide feedback that helps scientists further refine these technologies or improve their adoption.

*Indian farmers visiting IAC know a good sorghum when they see one.*

**India** The Andhra Pradesh Agricultural University, the Department of Agriculture, and ICRISAT together organized a Farmers' Day at Pallagutta in Warangal district in October. Over 60 farmers visited an on-farm trial of short-duration pigeonpea, and discussed the problems they faced while growing the crop.

The first ever postrainy-season Farmers' Day at IAC was held in January 1995. Ready-to-harvest chickpea fields—experimental plots at IAC and farmers' fields (with NARS/ICRISAT varieties) just outside the boundary fence—were the major attraction. There were also demonstration plots of sorghum, pearl millet, and groundnut, and question-and-answer sessions in five languages. Another feature was a hugely popular song and dance performance by a vaudeville troupe that tours villages in Andhra Pradesh to promote IPM.

**Kenya** ICRISAT and KARI jointly held two Field Days—at the KARI substation at Alupe in western Kenya in July 1994, and in a farmer's field in Kali in February 1995. The main purpose of the Alupe Field Day was to demonstrate different finger millet and sorghum varieties, and obtain feedback from farmers. About 100 farmers participated, as did local government officials, schoolchildren, and 150–200 extension staff. Sixty-five farmers, including 30 women, attended the Field Day at Kali. They were shown trials of short-duration pigeonpea lines and improved cropping systems for long-duration pigeonpea. One outcome of the discussions between farmers and scientists was that farmers now plan to form groups to buy crop protection equipment.

**Mali** Three Field Days were held at ICRISAT's research station in Samanko in October; two for NARS scientists who had earlier participated in training courses at

Samanko, and one for farmers and extension staff. Fifteen entomologists from Mali and Senegal visited field experiments on head bug resistance and pest management practices. Thirty-seven sorghum scientists from eight Francophone countries (Benin, Burkina Faso, Côte d'Ivoire, Guinea, Mali, Niger, Senegal, and Togo) visited field sites and laboratory facilities where sorghum improvement work (variety development and photoperiod studies) were in progress. Visitors on the third Field Day included 16 farmers and 9 extension agents, who were shown around experimental plots and advanced sorghum yield trials. Limited quantities of Nazongala (an improved local variety) were distributed, and will be sown in farmers' fields in the 1995/96 cropping season.

**Namibia** A Field Day organized by the Namibian NARS at Mahanene in March was attended by over 200 participants, including government officials, research administrators, extension workers, and university lecturers. The Field Day focused on Okashana 1, a NARS/ICRISAT pearl millet variety that was released in Namibia in 1989, and has the potential to play a major role in improving food security in northern Namibia.

**Niger** A record 691 visitors, including 241 women farmers, attended three Field Days held at ISC in August. The farmers (from 79 villages and three different linguistic groups) were shown pearl millet, groundnut, and resource management experiments at the Sadoré research station. Their questions and comments were collated, and are being incorporated into an interactive database compatible with geographic information systems. The database will help ISC scientists characterize and target individual regions and groups for more effective technology exchange.

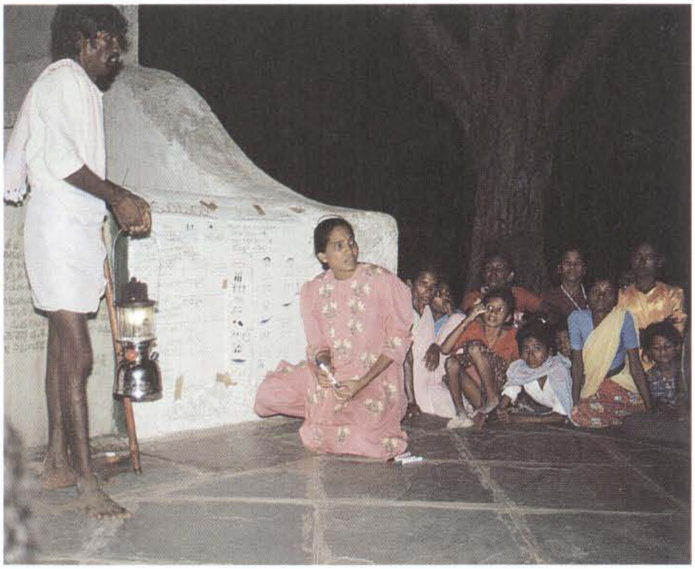
Probably the most gratifying aspect was the level of interest shown by the women farmers. The benefits of organizing Field Days exclusively for women—day three was for women only—are likely to be far-reaching because they play a crucial role in crop management, especially of such food crops as groundnut and pearl millet. The Field Days were widely covered by the local press, and were screened on the national television network for over 30 minutes. This led to so many requests for more such events that three additional Field Days were held in September for extension agents and farmers.

*In any language that's an impressive head of pearl millet. Farmers at an ISC Field Day agree.*

**Nigeria** Two Field Days were held at Kano in September and October. The first was for extension staff of the Kano State Agricultural and Rural Development Authority (KNARDA) and grain procurement staff of Guinness Nigeria. The Kano-based staff of the International Institute of Tropical Agriculture (IITA) also attended. The visitors were excited by the prospect of two NARS/ICRISAT sorghum varieties (one of which is highly suitable for malting) and two hybrids which will be released in Nigeria in 1995. The October Field Day was for scientists from the Institute for Agricultural Research (IAR). Fourteen IAR scientists participated—the largest gathering of IAR staff ever at Bagauda.

## Weighing up the benefits

Over the years, ICRISAT scientists have produced a wide range of research outputs. Some (e.g., improved cultivars) are used directly by farmers. Others are 'indirect' outputs for NARS use—breeding lines and parental material for crop improvement programs, standardized screening methods for disease or pest resistance, etc. But how popular are ICRISAT's research products, and what has been their impact on our clientele?



Barbara Adolph

*No ivory towers—ICRISAT socioeconomists work closely with villagers to ensure that research is driven by farmers' needs.*

Impact assessment is a new initiative in the Institute's research agenda. ICRISAT economists are in the process of quantifying the impact of the Institute's programs on efficiency, food security, poverty, equity, nutrition, risk and stability, sustainability, and gender. 'Target' cultivars and technologies (essentially a representative sample of ICRISAT's research outputs) have been identified, and their adoption and impact will be assessed under the ECON1 project. The studies use data collected from various sources—interviews with farmers, seed companies, government departments, other organizations involved in agricultural research and extension, and from published literature. Preliminary results show clearly that ICRISAT research products have had substantial impact, and that the payoffs far exceed the research investment required to generate them.

## Improved varieties in India


*Millet* rotis *are a staple food in Rajasthan. WC-C75 is the most widely grown pearl millet variety in the state.*

**WC-C75** Rajasthan accounts for about 45% of India's pearl millet area and nearly a quarter of the total production. Figures on seed sales by the Rajasthan State Seeds Corporation show that WC-C75 has been the most popular improved cultivar in the state since 1987/88, when it accounted for 33% of the pearl millet seed sold in Rajasthan. Since then its share has increased even further—59% in 1989/90, 69% in 1990/91. That year, the area sown to WC-C75 was estimated at 425,000 ha—35% of the total area under high-yielding varieties, and about 9% of the total pearl millet area in Rajasthan.

**ICPL 87** Farmers in Maharashtra (PS7 and 8) are switching from traditional pigeonpea varieties to improved short-duration ones. The most successful of these is ICPL 87 (released in 1986 as Pragati, meaning progress), which now covers nearly 150,000 ha in the state. Seed sales have shot up—the Maharashtra State Seeds Development Corporation sold 13 t in 1987, and over 1000 t (close to 80% of its pigeonpea seed sales) in 1994. ICPL 87 is popular with farmers for a variety of reasons. It can be grown as a rainy-season sole crop in drought-prone areas, allowing time for a second crop in the postrainy season. Multiple flushes can be harvested, which means less risk of total failure due to *Helicoverpa* infestations or a drought spell. ICPL 87 is also becoming popular in northern Karnataka, where 17 t of seed were sold in 1993.

**ICP 8863** Another big success is ICP 8863 (released as Maruti in 1986), a wilt-resistant pigeonpea cultivar targeted at the wilt-endemic areas of Karnataka, Maharashtra, and Andhra Pradesh (PS7). Large-scale adoption has been confirmed by recent surveys. ICP 8863 dominates the large pigeonpea tracts of Karnataka, occupying over 100,000 ha, about 18% of the pigeonpea area in the state. Seed sales by the Karnataka State Seeds Corporation increased from 49 t in 1990 to 140 t (47% of their total pigeonpea seed sales) in 1994. ICP 8863 is also popular in parts of Maharashtra and Andhra Pradesh. A survey of 119 farmers from seven districts in Maharashtra showed that in 1993, ICP 8863 was sown on over 60% of the total pigeonpea area in these districts.

### Groundnut production technology

NARS/ICRISAT teams have been working for several years with groundnut farmers in India, to develop and demonstrate new production technologies to increase yields and improve resource management. A preliminary survey in Parbhani district in Maharashtra (PS7).showed increasing adoption of the raised-bed and furrow concept that ICRISAT is trying to popularize. Partial adoption of the nutrient and water management packages (farmers usually modified the recommended package slightly, depending on local needs and resources) has also been fairly widespread. Surveys in four districts in Maharashtra during the summer of 1994 indicate that the raised-bed and furrow system was used on about 25,000 ha, and that 60,000 ha of groundnut are treated with single superphosphate fertilizer. Improved varieties occupy about 75,000 ha in these districts.

Average groundnut yields were 2.3 t $ha^{-1}$ with the improved technology, in contrast to 1.6 t $ha^{-1}$ using traditional methods. Components of the technology package, especially the raised-bed and furrow, are also popular for other crops (chickpea, soybean, sorghum, pigeonpea, okra, and some minor legumes). Of the farmers surveyed, 15% used raised-beds and furrows to grow chickpea, and reported yield gains of 15–45%.

### LASIP impact

ICRISAT's Latin American Sorghum Improvement Program (LASIP) ran for 16 years, before it closed in December 1993. A preliminary study conducted in 1994 showed that the program had generated substantial benefits. To take just four countries in the region, Guatemala, El Salvador, Honduras, and Nicaragua: Between 1976 and 1993, a number of cultivars identified or bred by LASIP were released in these countries; and several were released and did well in more than one country. Almost *half* the sorghum area in Guatemala, 30% in Honduras, 21% in Nicaragua, and 20% in El Salvador is occupied by improved cultivars released through LASIP. In 1993 alone, farmers from these four countries harvested an extra US$ 18.3 million worth of grain by using the improved varieties. The average annual LASIP research budget, in contrast, was US$ 0.35 million—proof that investment in agricultural research can lead to huge payoffs.

### Improved sorghum and pearl millet in Zimbabwe

New varieties of sorghum (SV 2) and pearl millet (PMV 2) were widely distributed in Zimbabwe for the first time in 1992. An adoption study in 1994 confirmed their wide acceptance—more than 30% of the country's smallholder sorghum area is now occupied by SV 2 and over 25% of the pearl millet area by PMV 2, and adoption is increasing.

Farmers at first grew a mixture of improved varieties and traditional landraces, perhaps as 'insurance' against drought. Currently, however, over one-third of SV 2 farmers have totally replaced landraces with improved varieties, and others are reducing the proportion of landraces in their fields. Over 40% of PMV 2 farmers have decided to stop growing landraces, and another 15% expect to reduce the area they sow to traditional varieties.

*Highlights from ICRISAT described some of ICRISAT's recent achievements. In such areas as biotechnology research, the benefits are long-term rather than immediate. In others, research results have reached farmers' fields quickly, and have led to significant, quantifiable benefits—higher yields, better crop management, more efficient use of resources, and higher incomes. ICRISAT and its collaborators in national programs and mentor institutions will continue to work closely together, building on these successes to generate new technologies to improve the lives of smallholder farmers throughout the semi-arid tropics.*

| Variety/Hybrid | Country | Notes |
| --- | --- | --- |
| **Sorghum** | | |
| Mahube | Botswana | Introduced by SMIP as SDS 2583—individual plant selections made in Botswana |
| Phofu | Botswana | Also known as Macia; introduced by SMIP as a semi-pure line from IAC, improved by single-plant selection in Zimbabwe and Mozambique |
| BSH 1 (SDSH 48) | Botswana | Hybrid, developed at Matopos by SMIP in collaboration with NARS |
| **Pearl millet** | | |
| ICTP 8203 | Karnataka (India) | An early, bold-seeded, mildew-resistant cultivar previously released in Andhra Pradesh, Maharashtra, and Punjab in India, and in Namibia (as Okashana 1) |
| Benkadi Nio (ICMV-IS 88102) | Mali | Released in Burkina Faso in 1993. Released in Mali as Benkadi Nio, meaning 'friendship millet' |
| ITMV 8001 | Chad | Identified by a UNDP/FAO project working with the Ministry of Agriculture and Environment |
| GB 8735 Rijal el Ghaiss | Chad and Mauritania | Sown by over 10,000 Chadian farmers in 1994. Named Rijal el Ghaiss—'harbinger of good fortune and happiness'—in Mauritania |
| SOSAT-C88 | Mauritania | Recommended for general cultivation |
| **Pigeonpea** | | |
| Hybrid CoH-1 (IPH 732) | Tamil Nadu (India) | Released by Tamil Nadu Agricultural University (TNAU) |
| Hybrid PPH-4 | Punjab (India) | Released by Punjab Agricultural University |
| MN 1 (ICPL 83004)<br>MN 5 (ICPL 85010)<br>MN 8 (ICPL 85024) | USA | Extra-short duration selections identified by the University of Minnesota and released in early 1995 |
| ICPL 86005<br>ICPL 84023<br>ICPL 85010 | USA | Identified for release by the University of Georgia |

| Variety/Hybrid | Country | Notes |
|---|---|---|
| **Chickpea** | | |
| ICCV 2 | Myanmar | Released for rice-based cropping systems—short and dry season, extra-short duration kabuli variety |
| ICCC 42 | Myanmar | Released for irrigated/lowland areas, short- to medium-duration |
| Bina Sola 2 (ICC 4998) | Bangladesh | Released for seed size and yield |
| Myles (ICCX 860047-BP-20H-BP-B) | USA (Washington, Idaho, Oregon) | Upright, medium tall, light brown seed, high-yielding desi type resistant to ascochyta blight and fusarium wilt |
| Damla (FLIP 85-7C)<br>Azizyie (FLIP 84-15C) | Turkey | Released by Turkish NARS; developed by the ICARDA/ICRISAT collaborative program |
| Dwelley (Surutato × FLIP 85-58C)<br>Sanford (Surutato × FLIP 85-58C) | USA | Bred at Washington State University using parental material from ICARDA/ICRISAT |
| **Groundnut** | | |
| ALR 2 (ICG 86011) | Tamil Nadu (India) | Released by TNAU for rainy-season cultivation in the Pollachi tract |
| BSR 1 (ICGV 86143) | Tamil Nadu (India) | Released by TNAU for rainy-season cultivation in the western zone |
| ICGV 86325 | India | Released jointly by ICAR and ICRISAT for rainy-season cultivation in southern Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala |
| BARD 92 [ICGS (E) 56] | Pakistan | Released by the Pakistan Agricultural Research Council |
| Stella (ICGV-SM 85048)<br>Veronica (ICGV-SM 86715) | Mauritius | Released by the Mauritius Sugar Industry Research Institute |

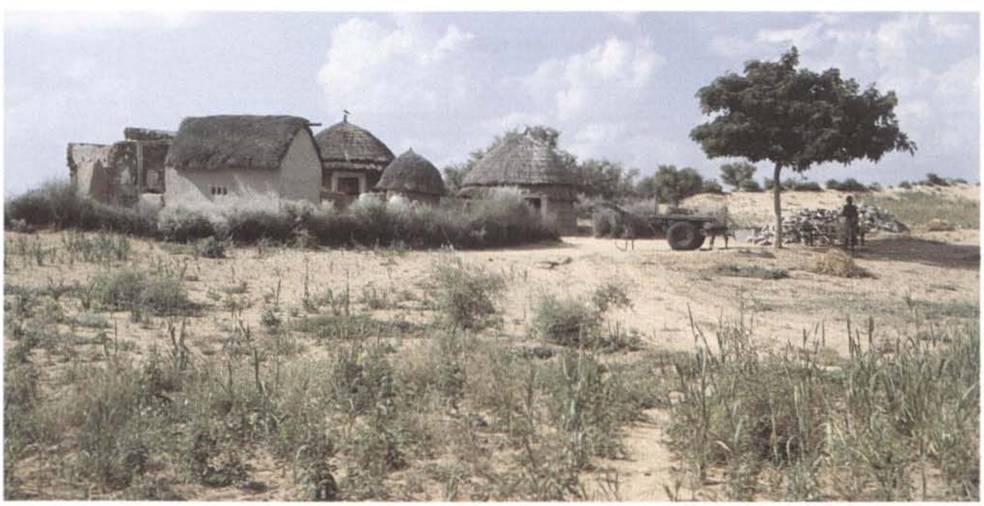
T G Kelley

## Research Project Portfolio

ICRISAT's research portfolio contains 22 multidisciplinary projects—15 commodity projects on five crops (pearl millet, sorghum, chickpea, pigeonpea, and groundnut), 4 integrated systems projects that focus on multi-commodity systems, 2 projects on socioeconomics and impact assessment, and a genetic resources project. All the projects involve close collaboration with NARS and wherever necessary, with mentor institutions that have expertise in basic research. Research activities span a continuum—diagnostic, strategic, applied, and adaptive work. This ensures that our work is focused on our clients (farmers and NARS throughout the SAT), and that technology exchange is rapid and effective.

The broad objectives of our research portfolio are to—

- Develop cultivars resistant/tolerant to the major biotic and abiotic stresses, and well adapted to target production systems.
- Effectively deliver research products and disseminate information through training programs, workshops, seminars, publications, and field days.
- Monitor the adoption of new and existing technologies to ensure that research activities are accurately targeted, and are responsive to the needs of both farmers and the NARS.
- Build upon collaborative research partnerships with NARS to address specific regional concerns, and simultaneously to maximize spillover benefits across the SAT.
- Ensure sustainable improvements in productivity, while conserving the natural resource base and improving the quality of the environment.



M M Anders

## Pearl Millet

### PM1 Improvement of pearl millet productivity and stability in arid to semi-arid tropical transition environments

Pearl millet production in the target regions is constrained by several factors—*Striga*, downy mildew, insect pests (especially the head miner and stem borer), drought, high temperatures, and the low yield potential of traditional landraces. PM1 will build on earlier work and on current studies under PM2 and PM3, to develop technologies to overcome these constraints. The objectives are to minimize grain yield losses, primarily through the use of host-plant resistance and other management strategies. Molecular techniques will be developed at IAC to characterize pathogen populations and to tag genes conferring resistance to downy mildew and high temperatures; the focus will then shift to utilizing these genes in genotypes suitable for the target production systems.

### PM2 Improvement of pearl millet productivity and stability in semi-arid tropical environments

This project addresses the major constraints (downy mildew, drought, low yield potential and poor adaptability, *Striga*, and insect pests) in an agroecology accounting for about 35% of the world's pearl millet production. The objectives are to improve productivity and sustainability, and to minimize losses through genetic enhancement and the development of integrated management practices. A continuum of basic/strategic to applied/adaptive research is planned, with close linkages to the other PM projects. Basic/strategic research will be conducted largely at IAC, and applied/adaptive work in WCA (ISC, Niger, Mali, and Nigeria), and SEA (Zimbabwe, Kenya). PM2 involves close collaboration with NARS and mentor institutions, particularly on molecular characterization and the use of genetic markers.

### PM3 Improvement of pearl millet productivity and stability in long-season semi-arid tropical environments

Long-duration pearl millet is an integral component of crop/livestock production systems in PS15, where soils are commonly acidic and infertile. Research activities will be centered at Kano, Nigeria, with support from ISC in Niamey, Niger. PM3 will draw heavily on outputs from PM1 and PM2, and will focus on applied and adaptive research in collaboration with NARS in Benin, Burkina Faso, Cameroon, Mali, Nigeria, and Senegal. The major thrust will be to develop, evaluate, and popularize improved long-duration cultivars that combine productivity and stability with adequate resistance/tolerance to the major stresses, especially downy mildew and low soil fertility. Shorter-duration varieties developed under PM1 and PM2 will also be evaluated.

| Project | | Asia | | | | | | | | | | | | Western and Central Africa | | | | | | Southern and Eastern Africa | | | | | | Latin America | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM1 | Target | 1 | | | | | | | | | | | | 13 | | | | | | 19 | | | | | | | | | | |
| | Spillover | | | | | | 6 | | | | | | 12 | | 14 | 15 | | | | | 20 | | | | | | | | | |
| PM2 | Target | | | 3 | | | | | 8 | | | | | | 14 | | | | | | 20 | | | | | | | | | |
| | Spillover | | 2 | | 4 | | 6 | 7 | | 9 | | | | | | | | | | | | | | | | | | | | |
| PM3 | Target | | | | | | | | | | | | | | | 15 | | | | | | | | | | | | | | |
| | Spillover | | | | | | | | | | | | | | | | | | | | 20 | | | | | | | | | |

## Sorghum

### SG1 Improvement of sorghum productivity and stability in low-rainfall areas

This is a regional project in SEA, targeting drought-prone areas characterized by sorghum/pearl millet based cropping systems. Approximately 2.55 million ha of rainfed sorghum is grown in such systems in Botswana, Kenya, Mozambique, Namibia, Somalia, Sudan, and Zimbabwe. Research will focus mainly on three areas—technology exchange and facilitation of seed multiplication and distribution; on-station and on-farm evaluation of improved cultivars and management options; and identification of farmers' preferences amongst different technologies and plant traits. The project will specifically target *Striga*, pests (particularly storage pests and stem borers), and drought by developing improved genetic materials and integrated management methods. Standardized laboratory techniques will also be developed to enable genotypes to be screened for *Striga* resistance.

### SG2 Improvement of sorghum productivity and stability in medium-rainfall areas

This is the key project in sorghum improvement within ICRISAT, and is closely linked to the other sorghum and integrated systems projects for the exchange of information, technologies, and materials. Research centers around four main areas—analysis of the importance of physical, biological, and economic constraints to increasing productivity; management of biotic constraints; trait-specific genetic enhancement of agronomically superior genotypes; and adoption and impact of the research products. SG2 will build upon the comparative advantages of regional opportunities, establish research partnerships in areas where NARS or advanced institutions are strong, and thus maximize spillover benefits across production systems and regions.

### SG3 Improvement of sorghum productivity and stability in high-rainfall areas

This is a regional project in WCA, where sorghum is a staple food crop in PS16, which extends across 12 countries. Although climatic and soil factors are relatively favorable, improvements in productivity have been small. Traditional cultivars are late-maturing and relatively low-yielding, while improved cultivars are vulnerable to a number of biotic constraints including grain molds, *Striga*, headbugs, and midge. SG3 will focus on the development of improved genetic materials and integrated management strategies against diseases, insect pests, and *Striga*. The project involves research partnerships CIRAD, which already has a sorghum improvement team working with ICRISAT in PS16, and with NARS in Burkina Faso, Benin, Cameroon, Chad, Côte d'Ivoire, Ghana, Mali, and Nigeria.

### SG4 Improvement of sorghum productivity and stability in high-altitude low-temperature areas

The cool highlands of tropical Africa—parts of Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, and Zaire—include some of the most densely populated areas on the continent. SG4 addresses this specialized ecological niche, in which sorghum is cultivated as a staple food crop on approximately 800,000 ha. The major constraints are low temperature and diseases. Because of the requirement of cold tolerance, potential spillover benefits from other projects are likely to be limited. The major objectives are to improve productivity, grain quality, and cold tolerance, and develop integrated management strategies against the major diseases. Collaborative breeding work and varietal testing with NARS are integral components of the project.

### SG5 Improvement of sorghum productivity and stability in postrainy-season production

This is a regional project within Asia (mainly India), where postrainy-season sorghum is grown on over 5.6 million ha in PS8 and parts of PS7. Productivity improvement in this crop is a priority for the Indian NARS, who will be closely involved in SG5. The initial emphasis will be on strategic studies on adaptation. The major thrusts will include analysis of the importance of selected constraints; assessment of new approaches and opportunities for improving productivity and profitability; development of improved management strategies to reduce shootfly losses; improvement of breeding material using trait-based breeding methods; and an impact assessment of strategic research on postrainy-season sorghum.

| Project | | Asia | | | | | | | | | | | | Western and Central Africa | | | | | | Southern and Eastern Africa | | | | | | Latin America | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SG1 | Target | | | | | | | | | | | | | | | | | | | 19 | | | | | | | | | | |
| | Spillover | | | | | | | | | | | | | 13 | 14 | | | | | | 20 | | | | | | | | | |
| SG2 | Target | | | | 4 | | | 7 | | 9 | | | | | 14 | 15 | | | | | 20 | 21 | | | | | | | | |
| | Spillover | | | | | 5 | 6 | | | | | | | | | | | | | | | | | | | | | 27 | | 29 |
| SG3 | Target | | | | | | | | | | | | | | | | 16 | | | | | | | | | | | | | |
| | Spillover | | | | | | | | | | | | | | | | | 17 | | | | | 22 | | | | | | | |
| SG4 | Target | | | | | | | | | | | | | | | | | | | | | | | 23 | | | | | | |
| | Spillover | | | | | | | | | | | | | | | | | | | | | | | | 24 | | | | | |
| SG5 | Target | | | | | | | 7 | 8 | | | | | | | | | | | | | | | | | | | | | |
| | Spillover | | | | | | 6 | | | | | | | | | | | | | | | | | | | | | | | |

## Groundnut

Groundnut research will be conducted under three projects, each addressing a distinct agroecology. GN1 targets a largely subsistence level of production. GN2 focuses on areas where both subsistence and intensive farming are practiced, and GN3 on high-input intensive commercial production of groundnut. Because many constraints to productivity and adaptation are common to these agroecologies, all three projects share the resourcing of particular research activities, and exchange knowledge, technology, and material as appropriate. To increase cost-effectiveness, strategic work will be concentrated mainly at IAC, while applied and adaptive research will be carried out in Asia, WCA, and SEA.

**GN1 Improvement of medium- and long-duration rainfed groundnut productivity and stability**

**GN2 Improvement of short-duration rainfed groundnut productivity and stability**

**GN3 Improvement of irrigated postrainy-season groundnut productivity and stability**

The primary objective of each project is to improve productivity and stability of groundnut production. Research activities are grouped under seven subprojects, which form the components of each project (except for Management of drought, which involves only GN1 and GN2).

- **Management of foliar diseases**—risk prediction, development of resistant, high-yielding material, identification and subsequent use of molecular markers and probes to identify resistance sources, development and popularization of management 'packages' for foliar diseases.
- **Management of foliar pests**—development and utilization of biological control techniques against *Spodoptera* and leaf miner, management schemes to control insecticide resistance, development and testing of pest-resistant genotypes, development and popularization of integrated pest management (IPM) methods.
- **Management of aflatoxin**—assessment of aflatoxin contamination in various production systems, development and testing of resistant genotypes and on-farm management options against aflatoxin contamination, adoption and impact analysis.
- **Management of viruses and sucking pests**—development of diagnostic tools for peanut clump, peanut mottle, peanut stripe, and groundnut rosette viruses, development and testing of resistant genotypes, use of molecular markers for groundnut rosette virus resistance, integrated virus disease management.
- **Management of soil pests**—identification of soil pests, studies on pest distribution, identification and utilization of sources of resistance to nematodes, location-specific IPM for the control of soil pests.
- **Management of drought**—identification of genotypes with high water-use efficiency and high-temperature tolerance, studies on the use of molecular markers to tag drought-resistance traits, development and popularization of an integrated drought-management package.
- **Yield and adaptation**—development, testing, and distribution to NARS of material with multiple resistance, identification of zones of adaptation, genetic studies of traits related to adaptation, quality, and yield.
- **Information and technology exchange**—dissemination of information through the *International Arachis Newsletter* and Information and Research Bulletins, technology exchange with NARS through workshops, seminars, and training courses.

| Project | | Asia | | | | | | | | | | | | Western and Central Africa | | | | | | Southern and Eastern Africa | | | | | | Latin America | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GN1 | Target | | | | | | 6 | | 8 | 9 | | 11 | | 13 | 14 | | | | | | 20 | | | | | | | | | |
| | Spillover | | 2 | 3 | | 5 | | 7 | | | | | | | | 15 | 16 | | 18 | | | | 22 | | | | | | | |
| GN2 | Target | | | | | 5 | 6 | | 8 | 9 | 10 | 11 | | 13 | | | | | | | | | 22 | | | | | | | |
| | Spillover | | 2 | 3 | | | | 7 | | | | | | | 14 | | | | | | | 21 | | | | | | | | |
| GN3 | Target | | | | | 5 | | | | 9 | 10 | 11 | | | | | | | | | | | | | | | | | | |
| | Spillover | | 2 | 3 | 4 | | 6 | 7 | 8 | | | | | | | | | | | | | | | | | | | | | |

## Pigeonpea

### PP Enhancement of productivity, stability, and adoption of short-duration pigeonpea, and technology transfer in medium- and long-duration pigeonpea

Pigeonpea research has been consolidated into a single project, with primary emphasis on the improvement of short- and extra-short duration genotypes. The main objectives are to enhance yield and stability by developing durable resistance to the major biotic and abiotic constraints, integrated management methods against pests and diseases, and by improving adaptation. The expected outcomes—stable cytoplasmic male-sterility and restoration systems to enhance the use of hybrid cultivars, improved adaptation to drought-stressed environments, disease- and nematode-resistant lines, an integrated management system for *Helicoverpa armigera*, and improved genetic material for use in a range of production technologies developed for the target production systems. Core-funded research will be complemented by two externally funded projects based in Sri Lanka (funded by the Asian Development Bank) and in SEA (funded by the African Development Bank)

| Project | | Asia | | | | | | | | | | | | Western and Central Africa | | | | | | Southern and Eastern Africa | | | | | | Latin America | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PP | Target | | 2 | 3 | | | | 7 | 8 | 9 | | | | | | | | | | | 20 | 21 | | | | | | | | |
| | Spillover | | | | 4 | 5 | 6 | | | | 10 | | | | | 15 | 16 | | | | | | 22 | | | 25 | | 27 | 28 | |

## Chickpea

### CP1 Chickpea improvement and management in dry and hot environments

The primary objective is to improve stability and productivity in the target production systems, which account for approximately 45% of global chickpea production. The major thrusts are on the management of drought, insect pests, and soilborne diseases, impact assessment (which will also involve assessments of farmers' preferences), and genetic enhancement. The major outcomes will be higher and more stable yields through improved adaptation to drought-stressed environments, wider resistance to and integrated management of pests and diseases, and higher yield potentials.

### CP2 Chickpea improvement and management in moderately dry and cool environments

CP2 targets an agroecology that currently accounts for over 50% of world chickpea production. However, area and production are declining, largely because of farmers' perceptions of high risk as a consequence of unstable yields. Several constraints are important—chilling injury, inadequate nitrogen nutrition, botrytis gray mold, stunt virus disease, and other biotic stresses (ascochyta blight, soilborne diseases, pod borer, nematodes). Research will focus on improving genetic yield potential, integrated pest and disease management, and identification and incorporation of cold tolerance and enhanced biological nitrogen fixation in adapted materials. The objective is to stabilize chickpea yields, for example by developing new farming systems for double cropping and for non-traditional areas.

### CP3 Chickpea improvement and management in moderately dry and cold environments

The WANA region (PS12) accounts for about 18% of world chickpea production. The major constraints are ascochyta blight, nematodes and (for winter-sown crops) damage by freezing cold. CP3 will focus largely on ascochyta blight and the cyst nematode. Using molecular characterization and gene marking, genes conferring blight resistance will be identified and incorporated, in combination with cold tolerance and other adaptive traits. Nematology research will target genes for resistance to cyst and root-knot nematodes (the latter are important in northern India), transfering resistance to the cyst nematode from wild species, and developing integrated management systems. The project will continue and build upon the long-standing collaboration between ICRISAT and ICARDA in chickpea improvement.

| Project | | Asia | | | | | | | | | | | | Western and Central Africa | | | | | | Southern and Eastern Africa | | | | | | Latin America | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP1 | Target | | | | 4 | 5 | 6 | 7 | 8 | 9 | | 11 | 12 | | | | | | | | 20 | 21 | 22 | | | | | 27 | | |
| | Spillover | 1 | 2 | 3 | | | | | | | | | 12 | | | | | | | | | | | | | | | | | |
| CP2 | Target | 1 | 2 | 3 | | | | | | | 10 | 11 | | | | | | | | | | | | | | | | | | |
| | Spillover | | | | 4 | 5 | 6 | 7 | 8 | 9 | | | 12 | | | | | 17 | | 19 | 20 | | | | | 25 | | | | |
| CP3 | Target | | | | | | | | | | | | 12 | | | | | | | | | | | | | | | | | |
| | Spillover | 1 | 2 | 3 | | | | | | | | 11 | | | | | | | | | | | | | | | 26 | | | |

## Integrated Systems Projects

### ISP1 Strategies for enhanced and sustainable productivity in rainfed short-season (60–100 days) millet/legume based production systems

ISP1 is targeted at the drier desert margin areas of the semi-arid tropics—the southern margins of the Sahara, Southern Sahel, the eastern Thar desert, and parts of Botswana, Namibia, and Zimbabwe. The principal objectives are to improve productivity in traditional agro-sylvo-pastoral systems and arrest the degradation of the natural resource base. Improved genotypes, better management of nutrient and drought stresses, sustainable resource management technologies, and integrated management methods for pests, diseases, and weeds will be developed with extensive farmer participation. Other important components are crop-livestock interaction studies in collaboration with ILRI, and systems modelling in collaboration with mentor institutions. ISP1 is the link project for ICRISAT into the Desert Margins Initiative.

### ISP2 Strategies for enhanced and sustainable productivity in short- to intermediate-season (100–125 days) rainfed millet/sorghum/ legume based production systems

ISP2 targets an agroecology with predominantly sandy soils, a wide range of farming systems, and large livestock populations. Grain and stover yields are low, and sustainability is threatened by erosion of the resource base. The target production systems will be characterized in terms of physical, biological, and socioeconomic parameters. The project will focus on the introduction and evaluation of improved genetic materials, improvement of soil, water, and nutrient management, integrated management of pests, diseases, and weeds, and assessment of technology adoption and impact. Strategic research on productivity improvement and resource conservation will include modelling studies that will broaden the applicability of research results to other environments.

### ISP3 Strategies for enhanced and sustainable productivity in low- to intermediate-rainfall (90–150 days) production systems in the SAT

The diverse environments in these production systems are characterized by relatively large yield gaps between research stations and farmers' fields. ISP3 will develop and evaluate strategies for sustainable improvements in three areas—soil, water, and nutrient management and socioeconomic constraints to crop intensification in soils of high water-holding capacity; crop production on soils of low water-holding capacity; and integrated crop and soil management for postrainy-season crops. The results will be modelled and subsequently extrapolated to other environments, and the long-term implications of new technologies will be analyzed. Much of the research will be conducted at benchmark sites and farmers' fields in partnership with NARS, specialized institutions, and CIRAD (in WCA).

### ISP4 Legume-based technologies for rice and/or wheat production systems in South and Southeast Asia

Asia produces over 90% of the world's rice and around 30% of its wheat. To keep pace with population growth, production of these staples must rise by 2.5% per year. This in turn requires more detailed studies on cropping sequences, particularly on legume benefits in crop rotations. ISP4 has four major objectives—characterization of the system in terms of increases in legume use; collaborative research, with a systems focus, in areas of special expertise and comparative advantage; on-farm evaluation of improved technologies; and studies on adoption and impact of technologies. Modelling of research results will help to generate spillover benefits to other situations, assess impact on sustainability, and guide the research agenda. ISP4 is the link project for ICRISAT into the Rice-Wheat Consortium for the Indo-Gangetic plains.

| Project | | Asia | | | | | | | | | | | | Western and Central Africa | | | | | | Southern and Eastern Africa | | | | | | Latin America | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ISP1 | Target | 1 | | | | | | | | | | | | 13 | | | | | | 19 | | | | | | | | | | |
| | Spillover | | | | | | | | | | | | 12 | | 14 | | | | | | 20 | | | | | | | | | |
| ISP 2 | Target | | | | | | | | | 9 | | | | | 14 | | | | | | 20 | | | | | | | | | |
| | Spillover | | | | | | 6 | | | | | | | 13 | | 15 | | | | | | | | | | | | | | |
| ISP3 | Target | | | | | | | 7 | 8 | | | | | | | 15 | | | 18 | | | 21 | | | | | | | | |
| | Spillover | | | | | | | | | | | | | | 14 | | 16 | | | | 20 | | | | | | | | | |
| ISP4 | Target | | 2 | 3 | | 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Spillover | | | | 4 | | | | | | 10 | 11 | | | | | | | | | | | | | | | | | | |

## Socioeconomics and Impact Assessment

### ECON1 Research evaluation and impact assessment (REIA)

- Targets—global

ICRISAT has developed a range of technologies that are used widely in the SAT, either directly by farmers or as intermediate technologies by NARS and other organizations. Research evaluation and impact assessment are essential to account for past funding, justify continued donor support, and more importantly, provide information that will help scientists and research managers target research and allocate resources. ECON1 will integrate ex post impact assessment with ex ante priority setting in a dynamic framework. Research evaluation methodologies and databases will be developed for impact assessment and priority setting. Key research programs and networks will be assessed in terms of their contributions to productivity, food security, poverty, equity, nutrition, risk and stability, sustainability, and gender. Three major outcomes are expected—a quantitative and qualitative demonstration of the impact of collaborative NARS/ICRISAT research; better targeting of research; and an information system to help scientists and research managers prioritize research objectives and allocate resources among alternative options.

### ECON2 Markets and policy

- Targets—global

This project will examine the supply and demand prospects of ICRISAT mandate crops, and diagnose product and input market constraints limiting the use of improved technologies. There are three major activities—commodity situation and outlook, product markets and policy, and input markets and policy. The commodity situation and outlook work will examine production, trade, and utilization trends, and the factors which influence them. The product markets and policy subproject will study the impact of specific market policies on trade and prices. It will also examine price and non-price factors influencing the comparative advantage of ICRISAT crops, and assess the determinants of medium- to long-term supply and demand. Input markets and policy studies will focus on policy and infrastructural factors influencing the availability and use of inputs, particularly seed availability, which is frequently a major bottleneck.

## Genetic Resources

### GR Genetic resources assembly, evaluation, and management for conservation and utilization

- Targets—global

ICRISAT holds the world germplasm collections of its mandate crops, with over 111,000 accessions from 128 countries. However, further collection is necessary, particularly of wild relatives of these crops. Research activities will include characterization, preliminary evaluation, and documentation as databases; collection, biodiversity studies, and ecoregional surveys; ex situ maintenance and in situ conservation; and germplasm distribution and exchange. Particular emphasis will be placed on the collection of untapped wild relatives, and the use of agronomic traits and molecular markers in germplasm classification. There will be increasingly close interaction with other CGIAR centers as part of the Systemwide Genetic Resources Program.

## Production systems

### Asia

**1** Transition zone from arid rangeland to rainfed, short-season millet/pulse/livestock. *Eastern margins of the Thar Desert.*

**2** Subtropical lowland rainy and postrainy season, rainfed, mixed cropping. *Central/eastern Indo-Gangetic Plains.*

**3** Subtropical lowland rainy and postrainy season, irrigated, wheat-based. *Western Indo-Gangetic Plains.*

**4** Tropical, high-rainfall rainy plus postrainy season, rainfed, soybean/wheat/chickpea. *Central India.*

**5** Tropical, lowland, rainfed/irrigated, rice-based. *Eastern India, Myanmar, Thailand, Southeast Asia.*

**6** Tropical, lowland, short rainy season, rainfed, groundnut/millet. *Saurastra Peninsula.*

**7** Tropical, intermediate rainfall, rainy season, sorghum/cotton/pigeonpea. *Eastern Deccan Plateau, central Myanmar.*

**8** Tropical, low-rainfall, primarily rainfed, postrainy season, sorghum/oilseed. *Western Deccan Plateau.*

**9** Tropical, intermediate-length rainy season, sorghum/oilseed/pigeonpea interspersed with locally irrigated rice. *Peninsular India.*

**10** Tropical, upland, rainfed, rice-based. *Eastern India, Southeast Asia.*

**11** Subtropical, major groundnut and sorghum. *China.*

**12** Subtropical, intermediate elevation, winter rainfall and rainfed, wheat-based. *West Asia and North Africa.*

| Production System | Commodities | | | | | | | | | | | | | | | Integrated Systems | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PM | | | SG | | | | | GN | | | PP | CP | | | ISP | | | | ECON | | GR |
| 1 Target | 1 | | | | | | | | | | | | | 2 | | 1 | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | | 1 | | 3 | | | | | | | |
| 2 Target | | | | | | | | | | | | 1 | | 2 | | | | | 4 | 1 | 2 | 1 |
| Spillover | | 2 | | | | | | | 1 | 2 | 3 | | 1 | | 3 | | | | | | | |
| 3 Target | | 2 | | | | | | | | | | 1 | | 2 | | | | | 4 | 1 | 2 | 1 |
| Spillover | | | | | | | | | 1 | 2 | 3 | | 1 | | 3 | | | | | | | |
| 4 Target | | | | | 2 | | | | | | | | 1 | | | | | | | 1 | 2 | 1 |
| Spillover | | 2 | | | | | | | | | 3 | 1 | | 2 | | | | | 4 | | | |
| 5 Target | | | | | | | | | | 2 | 3 | | 1 | | | | | | 4 | 1 | 2 | 1 |
| Spillover | | | | | 2 | | | | 1 | | | 1 | | 2 | | | | | | | | |
| 6 Target | | | | | | | | | 1 | 2 | | | 1 | | | | | | | 1 | 2 | 1 |
| Spillover | 1 | 2 | | | 2 | | | 5 | | | 3 | 1 | | 2 | | | 2 | | | | | |
| 7 Target | | | | | 2 | | | 5 | | | | 1 | 1 | | | | | 3 | | 1 | 2 | 1 |
| Spillover | | 2 | | | | | | | 1 | 2 | 3 | | | 2 | | | | | | | | |
| 8 Target | | 2 | | | | | | 5 | 1 | 2 | | 1 | 1 | | | | | 3 | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | 3 | | | 2 | | | | | | | | |
| 9 Target | | | | | 2 | | | | 1 | 2 | 3 | 1 | 1 | | | | 2 | | | 1 | 2 | 1 |
| Spillover | | 2 | | | | | | | | | | | | 2 | | | | | | | | |
| 10 Target | | | | | | | | | | 2 | 3 | | | 2 | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | 1 | | | | | | | 4 | | | |
| 11 Target | | | | | | | | | 1 | 2 | 3 | | 1 | 2 | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | | | | | | | | 4 | | | |
| 12 Target | | | | | | | | | | | | | 1 | | 3 | | | | | 1 | 2 | 1 |
| Spillover | 1 | | | | | | | | | | | | 1 | 2 | | 1 | | | | | | |

## Western and Central Africa

**13** Transition zone from arid rangeland to short-season (less than 100 days), rainfed, millet/cowpea/livestock. *Sahelian western Africa, and southern margins of the Sahara Desert.*

**14** Intermediate season (100-125 days), rainfed, millet/sorghum/cowpea/groundnut-based. *Northern Sudanian Zone.*

**15** Intermediate season (125-150 days), rainfed, mixed, sorghum-based. *Southern Sudanian Zone.*

**16** Long-season (150-180 days), rainfed, mixed, maize-based. *Northern Guinean Zone.*

**17** Humid, bimodal rainfall, mixed, root crop based. *Southern Guinean and Forest Zones.*

**18** Low-lying areas prone to inundation, postrainy season, sorghum/millet/groundnut-based. *Sahelian and Sudanian Zones.*

| Production System | Commodities | | | | | | | | | | | | | | Integrated Systems | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PM | | | SG | | | | | GN | | | PP | CP | | | ISP | | | | ECON | | GR |
| 13 Target | 1 | | | | | | | | 1 | 2 | | | | | | 1 | | | | 1 | 2 | 1 |
| Spillover | | | | 1 | | | | | | | | | | | | | 2 | | | | | |
| 14 Target | | 2 | | | 2 | | | | 1 | | | | | | | | 2 | | | 1 | 2 | 1 |
| Spillover | 1 | | | 1 | | | | | | 2 | | | | | | 1 | | 3 | | | | |
| 15 Target | | | 3 | | 2 | | | | | | | | | | | | | 3 | | 1 | 2 | 1 |
| Spillover | 1 | | | | | | | | 1 | | | 1 | | | | | 2 | | | | | |
| 16 Target | | | | | | 3 | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | 1 | | | 1 | | | | | | 3 | | | | |
| 17 Target | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | 3 | | | | | | | | 2 | | | | | | | | |
| 18 Target | | | | | | | | | | | | | | | | | | 3 | | 1 | 2 | 1 |
| Spillover | | | | | | | | | 1 | | | | | | | | | | | | | |

## Southern and Eastern Africa

**19** Lowland, rainfed, short-season (less than 100 days), sorghum/millet/rangeland. *Sahelian eastern Africa, and margins of the Kalahari Desert.*

**20** Semi-arid, intermediate season (100-125 days), sorghum/maize/rangeland. *Eastern Africa and parts of southern Africa.*

**21** Intermediate season (125-150 days), sorghum/maize/finger millet/legumes. *Eastern and southern Africa.*

**22** Lowland, sub-humid, mixed, rice/maize/groundnut/pigeonpea/sorghum. *Coastal areas of eastern and southern Africa.*

**23** Highland, rainfed, long-season, (150-180 days), sorghum/maize/teff. *Highland zones of northeastern and eastern Africa.*

**24** Highland, semi-arid, rainfed, intermediate season (100-120 days), mixed maize/sorghum/wheat/barley/pastoral. *Highland zones of eastern and southern Africa.*

| Production System | Commodities | | | | | | | | | | | | | | Integrated Systems | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PM | | | SG | | | | | GN | | | PP | CP | | | ISP | | | | ECON | | GR |
| 19 Target | 1 | | | 1 | | | | | | | | | | | | 1 | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | | | 2 | | | | | | | | |
| 20 Target | | 2 | | | 2 | | | | 1 | | | 1 | 1 | | | | 2 | | | 1 | 2 | 1 |
| Spillover | 1 | | 3 | 1 | | | | | | | | 1 | | 2 | | 1 | | 3 | | | | |
| 21 Target | | | | | 2 | | | | | | | 1 | 1 | | | | | 3 | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | 2 | | 1 | | | | | | | | | | |
| 22 Target | | | | | | | | | | 2 | | | 1 | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | 3 | | | 1 | | | 1 | | | | | | | | | | |
| 23 Target | | | | | | | 4 | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | | | | | | | | | | | |
| 24 Target | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | 4 | | | | | | | | | | | | | | | |

## Latin America

**25** Tropical, upland, rainfed, maize/sorghum intercropping. *Central America and Hispaniola.*

**26** Tropical, intermediate elevation, subtropical summer rainfall, rainfed and irrigated, sorghum. *Inland valleys of Mexico and Colombia, northern Argentina.*

**27** Tropical and subtropical coastal plains, rainfed/irrigated. *Mainly Pacific coast of Central America.*

**28** Tropical, subhumid, rainfed, acid-soil savanna. *Llanos of Colombia and Venezuela.*

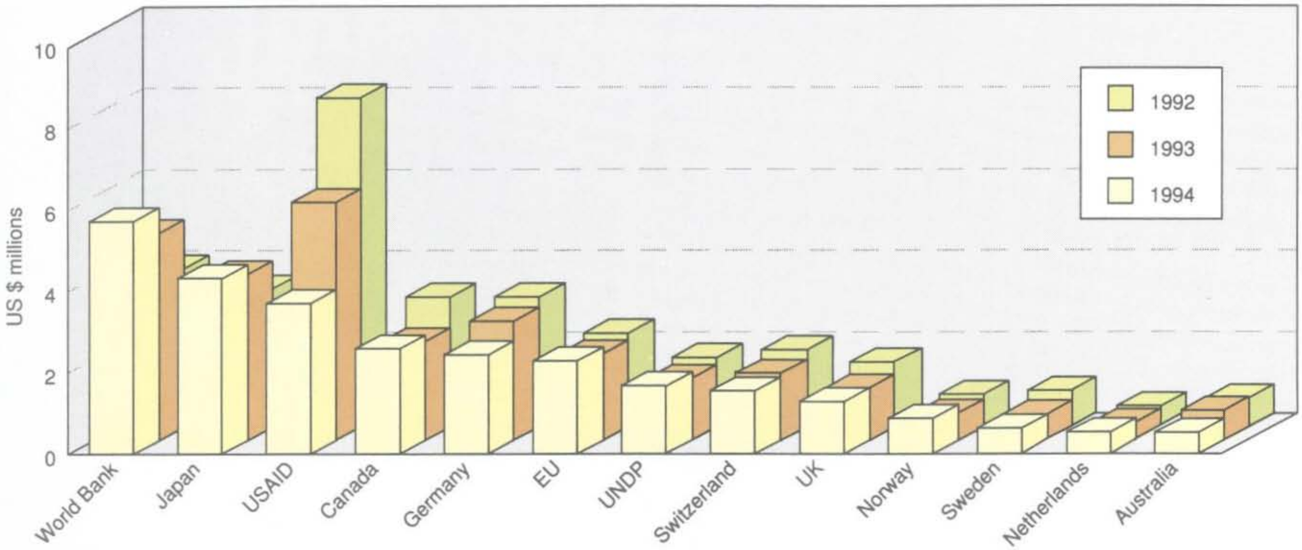
**29** Intermediate-elevation, semi-arid, rainfed, acid soil. *Northeastern and central Brazil.*

| Production System | Commodities | | | | | | | | | | | | | | | Integrated Systems | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PM | | | SG | | | | | GN | | | PP | CP | | | ISP | | | | ECON | | GR |
| 25 Target | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | 1 | | 2 | | | | | | | | |
| 26 Target | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | | | | 3 | | | | | | | |
| 27 Target | | | | | | | | | | | | | 1 | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | 2 | | | | | | | 1 | | | | | | | | | | |
| 28 Target | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | | | | | | | | 1 | | | | | | | | | | |
| 29 Target | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 |
| Spillover | | | | | 2 | | | | | | | | | | | | | | | | | |

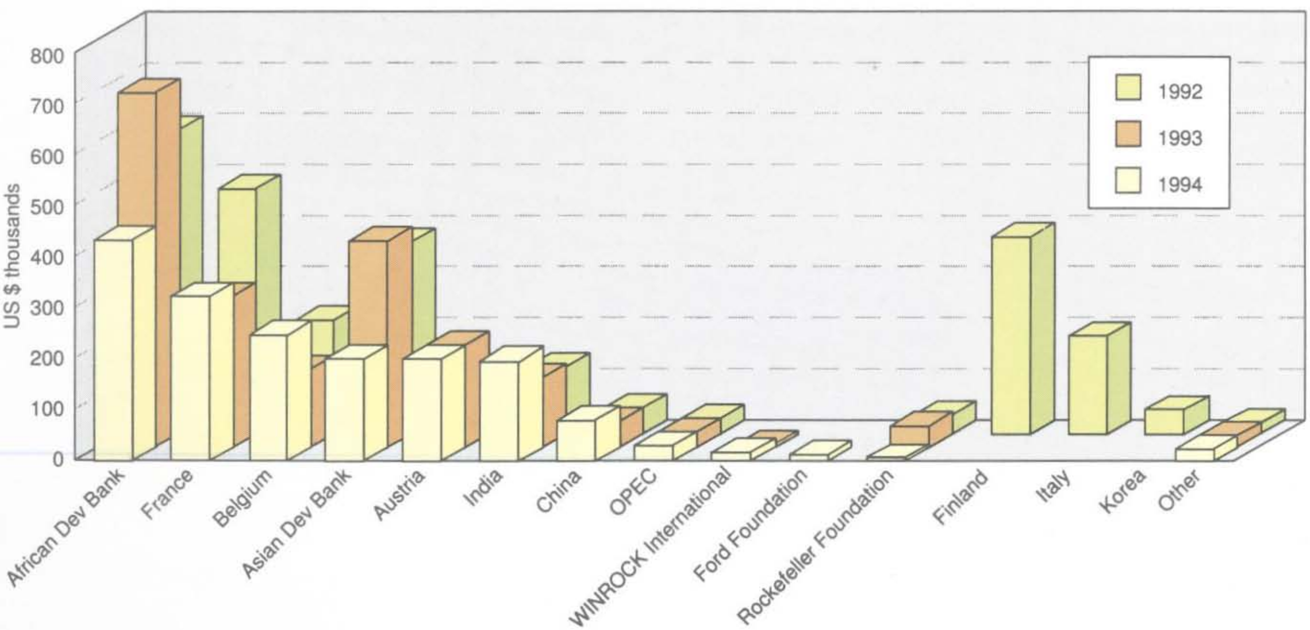
T G Kelley

## Donor Contributions (Core and Complementary)

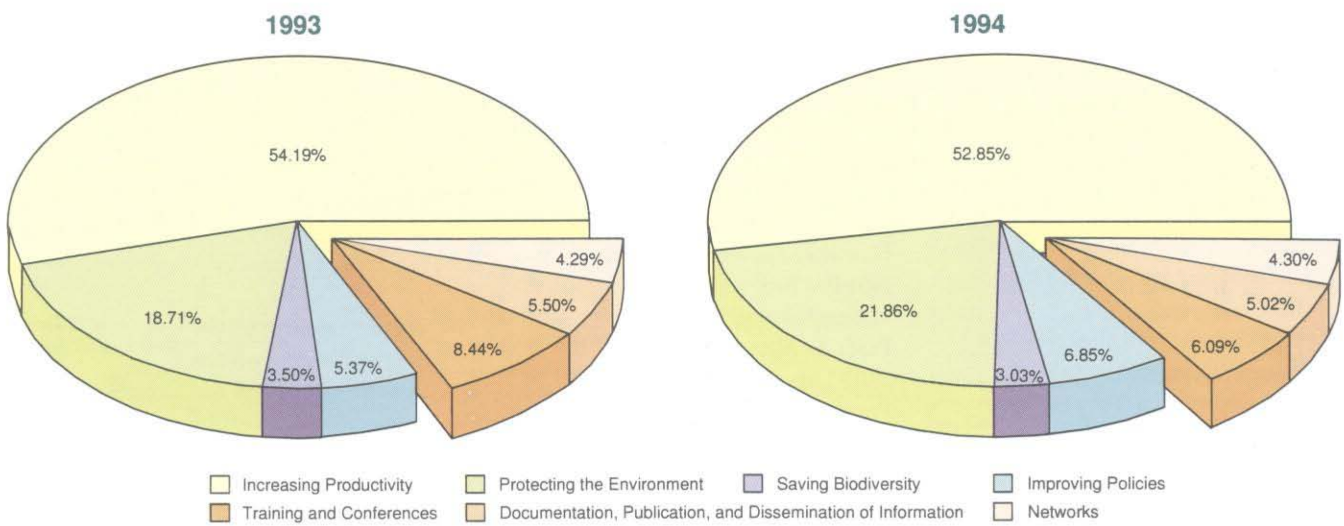
ICRISAT's work is supported by a large number of donors. The charts below indicate these donors in the sequence of their 1994 contributions. The charts also show the contributions from the same donors for 1993 and 1992.




The chart below is a continuation of the chart above, but with the vertical scale changed from US$ millions to US$ thousands.



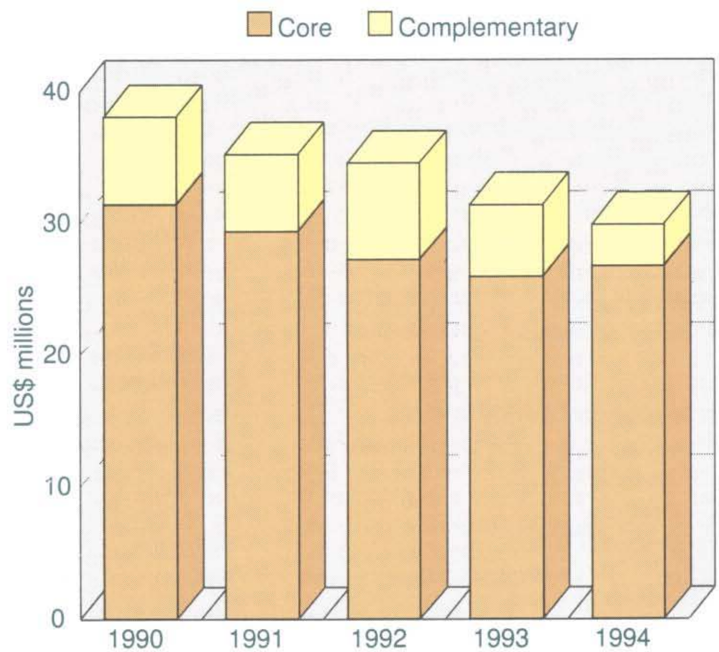
## Research and Research-related Expenditure (Core and Complementary)




## Balance Sheet

| | 1994 (US$ thousands) | 1993 (US$ thousands) |
|---|---|---|
| **Assets** | | |
| Cash and cash equivalents | 12 644 | 12 800 |
| Accounts receivable | 6 957 | 4 370 |
| Inventories | 1 443 | 711 |
| Prepaid expenses | 357 | 367 |
| Investments | 5 850 | 3 850 |
| Fixed assets – net | 42 323 | 50 951 |
| Other assets | 655 | 625 |
| **Total Assets** | 70 229 | 73 674 |
| **Liabilities** | | |
| Accounts payable – vendors and others | 1 793 | 3 727 |
| Accruals and provisions | 1 631 | 1 059 |
| Payments in advance from donors | 5 441 | 2 669 |
| In-trust funds | 35 | 43 |
| Long-term liabilities | 6 866 | 3 870 |
| **Net Assets** | | |
| Capital invested in fixed assets | 42 323 | 50 951 |
| Capital fund | 12 121 | 7 141 |
| Operating fund | (271) | 3 963 |
| Special purpose fund | 290 | 251 |
| **Total Liabilities and Net Assets** | 70 229 | 73 674 |

## Funding



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* We regret to announce that Dr Guitard died in office in February 1995. ICRISAT is grateful for his contributions to the Institute, and expresses its deep sympathy to his family.

*The listings presented here indicate the staff member's name, country of origin (in italics), designation, and work location (in bold type).*

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A Antonisamy, *India*, Senior Supervisor (Negative and Platemaking), **India**
Roberta H Gottfried, *USA*, Regional Information Officer, **Niger**
Susan D Hall, *UK*, Manager, Editorial Unit, **India**
L J Haravu, *India*, Senior Manager (Library and Documentation Services), **India**
Yateendra Joshi, *India*, Senior Editor, **India**
T R Kapoor, *India*, Assistant Manager (Composing), **India**
Eric M McGaw, *USA*, Public Awareness Officer, **India**
S Prasannalakshmi, *India*, Senior Library Officer, **India**
Upendra Ravi, *India*, Senior Production Officer (Video), **India**
S M Sinha, *India*, Manager (Art and Production), **India**
Ajay Varadachary, *India*, Editor, **India**

### Training and Fellowships Program

**B Diwakar**, *India*, Acting Program Leader, **India**
Djibo Y Abdoulkarim, *Niger*, Administrative Assistant, **Niger**
S K Dasgupta, *India*, Senior Training Officer, **India**
Faujdar Singh, *India*, Senior Training Officer, **India**

### Statistics

**Roger D Stern**, *UK*, Principal Statistician, **Niger**
K Vidyasagar Rao, *India*, Senior Statistician, **India**

### Administration

**Steven D Goode**, *USA*, Assistant Director (Administration), **India**
A Rama Murty, *India*, Senior Travel Officer, **India**

### Computer Services

S M Luthra, *India*, Manager (Systems and Operations), **India**
T B R Nagendra Gupta, *India*, Assistant Manager (Software), **India**
J Sai Prasad, *India*, Manager (Software), **India**

### Donor Relations

Jugu J Abraham, *India*, Senior Advisor, Donor Relations, **India**

### Finance

S Sethuraman, *India*, Assistant Finance Manager, **India**

### Purchase

C R Krishnan, *India*, Purchase and Stores Manager, **India**
D K Mehta, *India*, Assistant Purchase and Stores Manager, **India**

# Regional

## Asia Region

**Charles Renard**, *Belgium*, Executive Director, **India**

### Administration

K Jagannadham, *India*, Senior Transport Officer, **India**
Samiran Mazumdar, *India*, Assistant Manager (Food Services), **India**
P M Menon, *India*, Manager, RED Secretariat, **India**
Deepak M Pawar, *India*, Senior Scientific Liaison Officer, **India**
N Surya Prakash Rao, *India*, Chief Medical Officer, **India**
K K Sood, *India*, Chief Security Officer, **India**
P Suryanarayana, *India*, Assistant Personnel Manager, **India**

### Farm and Engineering Services Program

**D S Bisht**, *India*, Program Leader, **India**
K Ramesh Chandra Bose, *India*, Senior Engineer (Civil), **India**
P Rama Murthy, *India*, Senior Administrative Officer, **India**
Shiva K Pal, *India*, Manager (Plant Protection), **India**
R Parameswaran, *India*, Senior Engineer (Automobile), **India**
N S S Prasad, *India*, Chief Engineer (General Engineering Services), **India**
M C Ranganatha Rao, *India*, Deputy Chief Engineer (Farm Development and Construction), **India**
K Ravindranath, *India*, Manager (Farm Machinery and Mechanical Engineering Services), **India**
Marri Prabhakar Reddy, *India*, Assistant Manager (Irrigation, Labor, and Farm Maintenance), **India**
N V Subba Reddy, *India*, Senior Horticultural Officer, **India**
Ramesh C Sachan, *India*, Assistant Manager (Greenhouse and Controlled Environment, Training and Documentation), **India**

### Geographic Information System

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### Plant Quarantine

A M Ghanekar, *India*, Chief Plant Quarantine Officer, **India**

### Cereals and Legumes Asia Network (CLAN)

**C L L Gowda**, *India*, Principal Coordinator, **India**
A Ramakrishna, *India*, Scientist (Agronomy), **India**

## Western and Central Africa Region

**Karl Harmsen**, *Netherlands*, Executive Director, **Niger**

### Administration

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A R Dasgupta, *India*, Manager, Physical Plant Services, **Niger**
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Dramane Doumbia, *Mali*, Administrative Officer, **Mali**
Issa Garba, *Niger*, Manager, Purchase and Supplies, **Niger**
K A Moussa, *Niger*, Personnel Manager, **Niger**
G A Olaopa, *Nigeria*, Administrative Officer, **Nigeria**
Marou S Garba, *Niger*, Manager, Housing and Food Services, **Niger**
Delanne Solange, *Niger*, Executive Assistant, **Niger**

### Farm Services

**Bruno Gérard**, *Belgium*, Farm Manager, **Niger**

### West and Central Africa Sorghum Research Network (WCASRN)

**A Tenkouano**, *Burkina Faso*, Coordinator, **Mali**

### Réseau ouest et centre africain de recherche sur le mil (ROCAFREMI)

**L Cissé**, *Senegal*, Coordinator, **Niger**

## Southern and Eastern Africa Region

**Lewis K Mughogho**, *Malawi*, Executive Director, **Zimbabwe**

### Administration

**Nurdin S Katuli**, *Tanzania*, Acting Regional Administrator, **Zimbabwe**
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C C D Chagoma, *Malawi*, Administrative Officer, **Malawi**
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Irene Tapela, *Zimbabwe*, Senior Accountant, **Zimbabwe**

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Chibhamu M Matanyaire, *Zimbabwe*, Principal Station Management and Development Officer, **Namibia**

## Latin America and Caribbean Region

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# ICRISAT Senior Staff

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R P Thakur, *India*, Senior Scientist, **India**
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### Genetic Enhancement

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Doubt Gumbonzvanda, *Zimbabwe*, Senior Research Technician, **Zimbabwe**
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C Thomas Hash Jr, *USA*, Principal Scientist (Crop Coordinator, Pearl Millet), **India**
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Sanders Mpofu, *Zimbabwe*, Senior Research Technician, **Zimbabwe**
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A Babatunde Obilana, *Nigeria*, Principal Scientist (Crop Coordinator, Sorghum), **Zimbabwe**
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H Frederick W Rattunde, *USA*, Scientist, **India**
Belum V S Reddy, *India*, Senior Scientist, **India**
L J Reddy, *India*, Senior Scientist, **India**
J F Renno, *France*, Principal Scientist (ORSTOM), **Niger**
Henk A van Rheenen, *Netherlands*, Principal Scientist (Crop Coordinator, Chickpea), **India**
Daisy Salifu, *Malawi*, Research Associate, **Malawi**
K B Saxena, *India*, Senior Scientist, **Sri Lanka**
K B Singh, *India*, Principal Scientist, **Syria**
Laxman Singh, *India*, Principal Scientist (Crop Coordinator, Pigeonpea), **India**
Onkar Singh, *India*, Senior Scientist, **India**
S C Sethi, *India*, Senior Scientist, **India**
John W Stenhouse, *UK*, Principal Scientist (Crop Coordinator, Sorghum), **India**
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Solomon Tuwafe, *Ethiopia*, Senior Scientist, **Malawi**
H D Upadhyaya, *India*, Scientist, **India**
Eva Weltzien Rattunde, *Germany*, Scientist, **India**

### Genetic Resources

**Melak H Mengesha,** *Ethiopia*, Principal Scientist and Research Division Director, **India**
R P S Pundir, *India*, Senior Scientist, **India**
S Appa Rao, *India*, Senior Scientist, **India**
P Remanandan, *India*, Senior Scientist, **India**
A K Singh, *India*, Senior Scientist, **India**

### Socioeconomics and Policy

**David D Rohrbach,** *USA*, Principal Scientist and Research Division Director, **Zimbabwe**
Elias Ayuk, *Cameroon*, Agricultural Economist (ICRAF) **Mali**
J Baidu-Forson, *Ghana*, Principal Scientist, **Niger**
Kimberly R Chung, *USA*, Scientist, **India**
Ma Cynthia S Bantilan, *Philippines*, Principal Scientist, **India**
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Matthew Turner, *USA*, Sociologist (ILRI), **Niger**
K Ramadevi, *India*, Scientist, **India**
Meri L Whitaker, *USA*, Scientist, **India**
T O Williams, *Nigeria*, Economist (ILRI), **Niger**
Peter Xaba, *Zimbabwe*, Higher Research Technician, **Zimbabwe**

### Soils and Agroclimatology

**M V K Sivakumar,** *India*, Principal Scientist and Research Division Director, **Niger**
N K Awadhwal, *India*, Senior Scientist, **India**
A Bationo, *Burkina Faso*, Principal Scientist (IFDC), **Niger**
C Bielders, *Netherlands*, Research Fellow, **Niger**
J Brouwer, *Netherlands*, Principal Scientist (University of Wageningen), **Niger**
M C Klaij, *Netherlands*, Principal Scientist, **Ethiopia**
J V D K Kumar Rao, *India*, Senior Scientist, **India**
Kofi B Laryea, *Ghana*, Principal Scientist, **India**
Keuk-Ki Lee, *Korea*, Principal Scientist, **India**
F Mahler, *Germany* (University of Hohenheim), **Niger**
K Michels, *Germany*, Research Fellow, **Niger**
Prabhakar Pathak, *India*, Senior Scientist, **India**
K P C Rao, *India*, Scientist, **India**
T J Rego, *India*, Senior Scientist, **India**
Bjorn Seeling, *Germany*, Research Fellow, **India**
Piara Singh, *India*, Senior Scientist, **India**
N Vidyalakshmi, *India*, Visiting Scientist, **Niger**
S M Virmani, *India*, Principal Scientist, **India**
S P Wani, *India*, Scientist, **India**

## Awards and Distinctions

**C Fred Bentley**, first Governing Board Chairman, was awarded The Order of Canada—the highest honor conferred by the Canadian Government—in recognition of his services to agriculture.

**Max N Birrell**, Governing Board member, was awarded a Doctorate of Applied Science by the Royal Melbourne Institute of Technology.

**J S Kanwar**, Deputy Director General Emeritus, was honored by several institutions. He was named Founder Director of the Punjab Agricultural University. The National Academy of Agricultural Sciences, India, nominated him for the Dr K Ramaiah Medal for his "monumental contributions to soil science and agricultural research and development". Dr Kanwar was also invited to become a member of the New York Academy of Sciences.

**A K Murthy** was elected a Fellow of the Institution of Engineers (India).

**Y D Narayana** won the Dr K Ramakrishna Memorial Gold Medal of the University of Agricultural Sciences, Bangalore, for his performance as a doctoral student.

**Suresh Pande** was elected a Fellow of Indian Phytopathological Society.

**G V Ranga Rao** won the Hexamer Agricultural Research Foundation's Distinguished Fellow Award for his work on integrated pest management in groundnut.

**K N Reddy** was elected a Fellow of the Indian Society of Genetics and Plant Breeding.

**J G Ryan** was awarded a Doctorate of Science (*Honoris causa*) by the Chandra Shekhar Azad University of Agriculture and Technology.

**D V S S R Sastry** was elected a Fellow of the Indian Society of Genetics and Plant Breeding.

**S B Sharma** was nominated a Fellow of three professional societies—the Afro-Asian Society of Nematologists, the Plant Protection Association of India, and the Indian Phytopathological Society. He also won the Professor H M Shah Memorial Award instituted by the Nematological Society of India.

**M S Swaminathan**, first Governing Board Vice Chairman, won the 1994 Sasakawa Environment Prize instituted by the United Nations Environment Programme (UNEP), for his life-long contributions to protecting the environment.

**S M Virmani** was elected Chairman of Commission VI: Soil Technology of the International Society of Soil Science.

A 17-member joint **ICRISAT-NARS team** won the first Doreen Margaret Mashler Distinguished Scientific Achievement Award for successfully controlling downy mildew, the most serious pearl millet disease in Africa and the Indian subcontinent. The members of this team—K Anand Kumar, D J Andrews, S B Chavan, S C Gupta, C T Hash, R P Jain, Pheru Singh, K N Rai, S D Singh, B S Talukdar, and J R Witcombe from ICRISAT; K R Chopra, O P Govila, R L Kapoor, K L Vyas, and W R Lechner, from the NARS of India and Namibia; and W D Stegmeier from INTSORMIL.

### William T Mashler

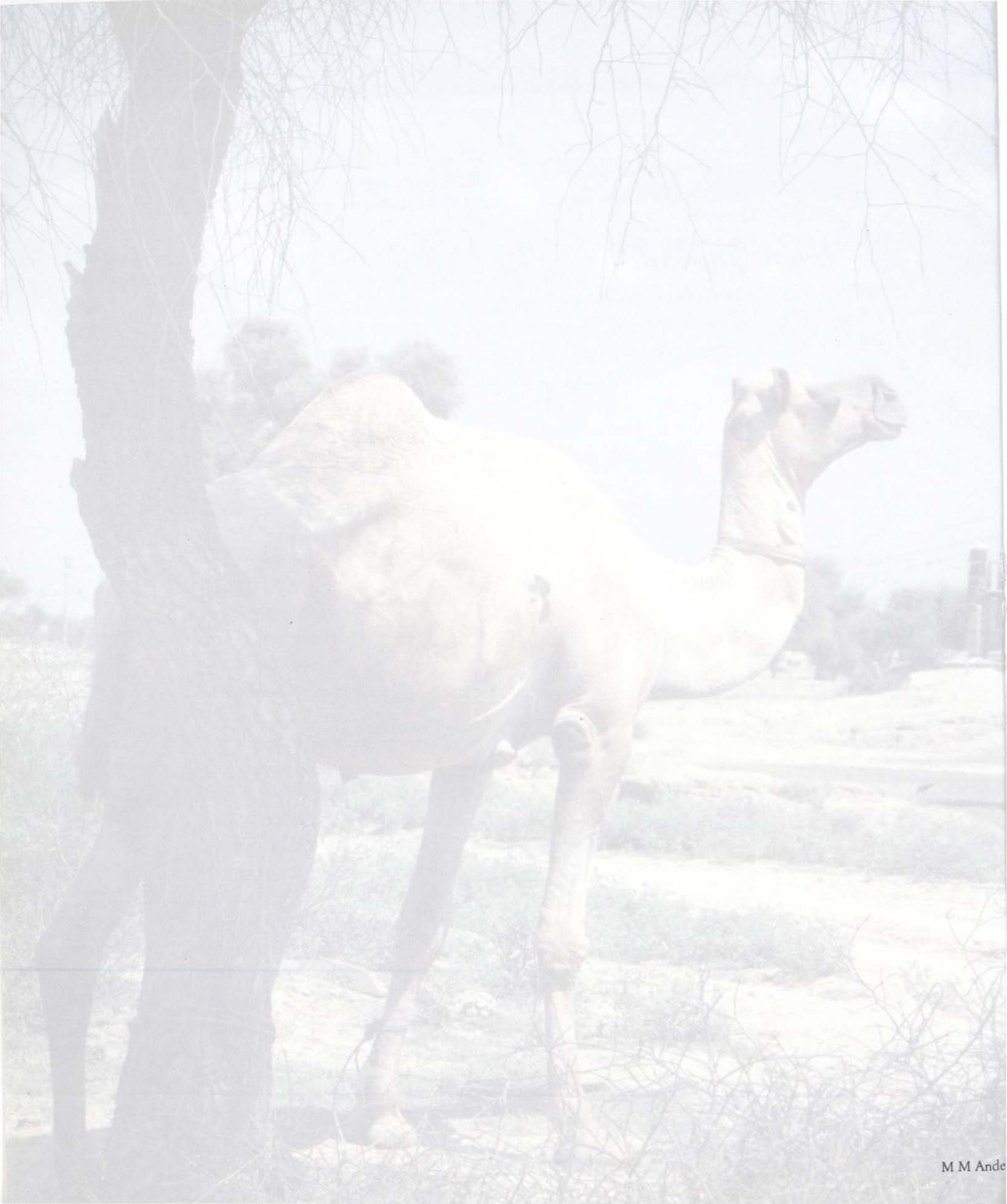

B D Hall

We announce with great regret that William T Mashler passed away on 3 August 1995, following a long illness. Dr Mashler was instrumental in ICRISAT's founding in 1972, and ever since, has had a special affection for, and close relationship with, this Institute. He served on its Governing Board from 1985 to 1992, the last 3 years as its Chairman. In 1992, he announced his donation to ICRISAT of the Doreen Margaret Mashler Distinguished Scientific Achievement Award in the name of his wife, who pre-deceased him by many years. We salute a formidable ally, and convey our deepest sympathy to his family.

# Acronyms

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| ASARECA | Association for Strengthening Agricultural Research in Eastern and Central Africa (Uganda) |
| AUA | Alemaya University of Agriculture (Ethiopia) |
| BMZ | Bundesministerium für Wirtschaftliche und Entwicklung Zusammenarbeit (Germany) |
| CENARGEN | Centro Nacional de Pesquisa de Recursos Genéticos e Biotechnologia (Brazil) |
| CFC | Common Fund for Commodities (Netherlands) |
| CGIAR | Consultative Group on International Agricultural Research (USA) |
| CIAT | Centro Internacional de Agricultura Tropical (Colombia) |
| CIFOR | Center for International Forestry Research (Indonesia) |
| CIMMYT | Centro Internacional de Mejoramiento de Maïz y Trigo (Mexico) |
| CIP | Centro Internacional de la Papa (Peru) |
| CIRAD | Centre de coopération internationale en recherche agronomique pour le développement (France) |
| CLAN | Cereals and Legumes Asia Network |
| CP1, 2, 3 | chickpea projects 1, 2, 3 |
| ECON1, 2 | socioeconomics/impact assessment projects 1, 2 |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations (Italy) |
| GN1, 2, 3 | groundnut projects 1, 2, 3 |
| GR | genetic resources project |
| GTZ | Deutsche Gesellschaft für Technische Zusammenarbeit (Germany) |
| IAC | ICRISAT Asia Center (India) |
| IAR | Institute of Agricultural Research (Ethiopia, Nigeria) |
| IARC | international agricultural research center |
| IBSRAM | International Board for Soil Research and Management (Thailand) |
| ICAR | Indian Council of Agricultural Research |
| ICARDA | International Center for Agricultural Research in the Dry Areas (Syria) |
| ICLARM | International Center for Living Aquatic Resources Management (Philippines) |
| ICRAF | International Centre for Research in Agroforestry (Kenya) |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics (India) |
| IER | Institut d'économie rurale (Mali) |
| IFDC | International Fertilizer Development Center (USA) |
| IFPRI | International Food Policy Research Institute (USA) |
| IIMI | International Irrigation Management Institute (Sri Lanka) |
| IITA | International Institute of Tropical Agriculture (Nigeria) |
| ILRI | International Livestock Research Institute (Ethiopia and Kenya) |

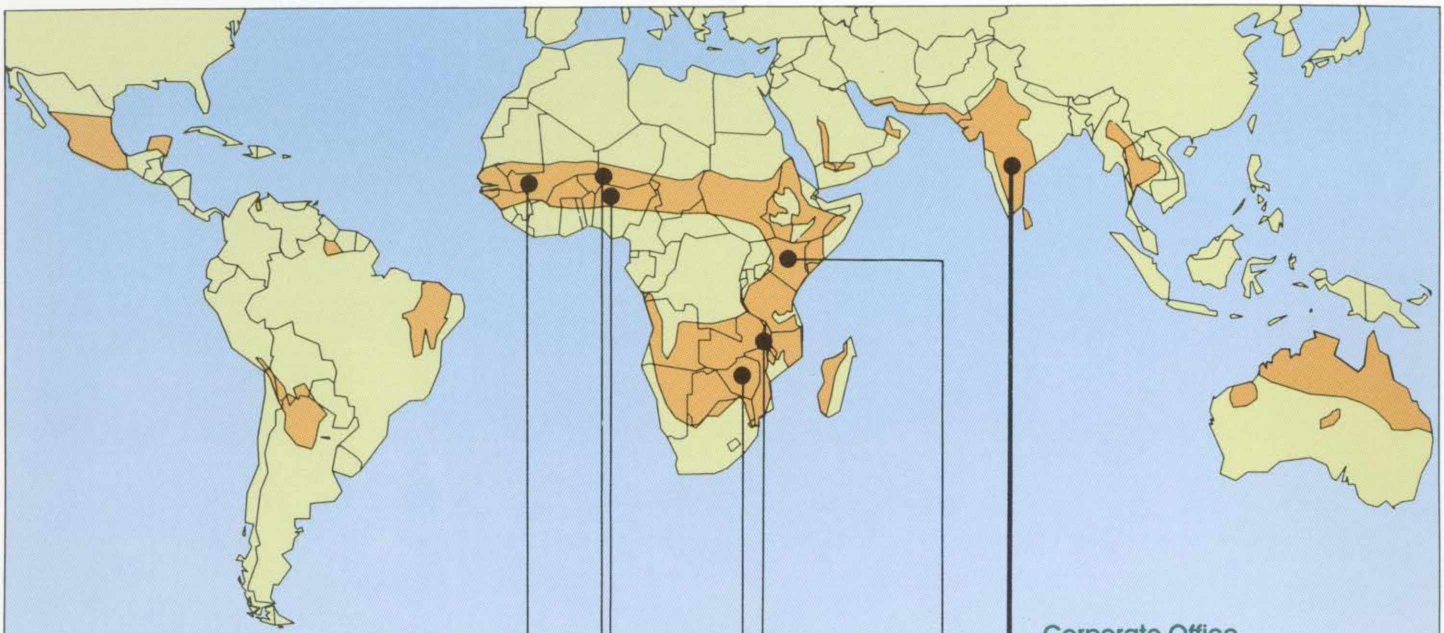
| | |
|---|---|
| INRAN | Institut national de recherches agronomiques du Niger |
| INTSORMIL | USAID Title XII International Sorghum/Millet Collaborative Research Support Program (USA) |
| IPGRI | International Plant Genetic Resources Institute (Italy) |
| IRRI | International Rice Research Institute (Philippines) |
| ISC | ICRISAT Sahelian Center (Niger) |
| ISNAR | International Service for National Agricultural Research (Netherlands) |
| ISP1, 2, 3, 4 | integrated systems projects 1, 2, 3, 4 |
| KARI | Kenya Agricultural Research Institute |
| KNARDA | Kano State Agricultural and Rural Development Authority (Nigeria) |
| LASIP | Latin American Sorghum Improvement Program (Mexico) |
| NARS | national agricultural research systems |
| NGO | non-governmental organization |
| NRI | Natural Resources Institute (UK) |
| ODA | Overseas Development Administration (UK) |
| OPEC | Organization of Petroleum Exporting Countries (Austria) |
| PM1, 2, 3 | pearl millet projects 1, 2, 3 |
| PP | pigeonpea project |
| PS1 to 29 | production systems 1 to 29 |
| QDPI | Queensland Department of Primary Industries (Australia) |
| ROCAFREMI | Réseau ouest et centre africain de recherche sur le mil (Niger) |
| SADC | Southern African Development Community (Botswana) |
| SAT | semi-arid tropics |
| SATCRIS | Semi-Arid Tropical Crops Information Service |
| SEA | Southern and Eastern Africa |
| SG1 to 5 | sorghum projects 1 to 5 |
| SMIP | Sorghum and Millet Improvement Program (Zimbabwe) |
| TNAU | Tamil Nadu Agricultural University (India) |
| UNDP | United Nations Development Programme (USA) |
| UNEP | United Nations Environment Programme (Kenya) |
| UNICEF | United Nations Children's Fund (USA) |
| USAID | United States Agency for International Development |
| WANA | West Asia and North Africa |
| WARDA | West Africa Rice Development Association (Côte d'Ivoire) |
| WCA | Western and Central Africa |
| WCASRN | West and Central African Sorghum Research Network (Mali) |



M M Ande

## ICRISAT's Mandate

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



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