ICRISAT Now

Sowing for the Future

International Crops Research Institute for the Semi-Arid Tropics

April 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.

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

April 1994

This report is published in lieu of an ICRISAT Report for 1993.
In addition to presenting highlights and achievements, it also
reports significant changes in organization and management
implemented during the first quarter of 1994.

Cover photograph *Sowing groundnuts in Vietnam*

Report from the Chairman and Director General

This past year has been a dynamic one for ICRISAT. In the early years of its third decade, the Institute is engaged in a major reorganization in order to serve its clients better. The reorganization is reflected in the structure of this 1993/94 report.

We first remind our readers of the particular challenges of the semi-arid tropics (SAT), a region it is our mission to serve, and then detail our reorganization and the rationale for change. In presenting the highlights of our work and achievements during the past year, we link various aspects of our research to production systems and to a broader, more global approach.

The major reasons for our reorganization have been the changes in ICRISAT's external environment, including reduced and uncertain funding, a situation that is affecting all centers throughout the Consultative Group on International Agricultural Research (CGIAR) system. In a research organization such as ICRISAT, new projects can be undertaken quite quickly if the resources are readily available. However, when it becomes necessary to cut costs, the time lag from decision to the subsequent realization of economies is considerable. Thus when faced with funding shortfalls and the necessity to rationalize programs and reduce staff and other resources, planning well in advance is essential.

ICRISAT did not receive information about its final core funding amount for the 1993 fiscal year until May, when 40% of the year's work had already been completed. By that time, it was virtually impossible to react effectively to the funding shortfall that was far more than we had anticipated. The result was an operating deficit for 1993. This deficit was smaller than it might have been, since in view of the funding uncertainty, we had only released interim budget allocations. ICRISAT's 1993 core funding was 4.7% less than in 1992. Over the last three years the overall reduction is 17.4%, and this is without considering inflation and currency exchange variations.

These changes have seriously affected our work. Both the volume and quality of research have been adversely affected by budget cuts for staff, equipment, and operations. The number of nationally recruited staff was 10% lower in 1993 than in 1991, and that of internationally recruited staff was down by 25% over the same period. For breeding units, it has meant fewer entries in breeding populations, smaller experimental areas, and reduced technology contributions. Other disciplines are conducting fewer and smaller trials on less land, have discontinued major projects, and have scaled down research activities.

Collaborative research and other international activities have also been cut back. Smaller travel budgets have affected interaction with national agricultural research systems (NARS) scientists, and some international collaborative research projects had to be cancelled. Our workshop and conference budget last year was less than half that of 1990. Human resource development programs have also been affected: for example, we hosted over 100 in-service trainees in 1989, but only 60 in 1993.

Partly as a result of funding cutbacks, in November 1993 the Governing Board approved the reorientation of the Institute's organization and management to emphasize the project as the basic unit of research. This change will devolve responsibility for all aspects of projects and move away from a hierarchical management system to one which emphasizes teamwork, scientific and socioeconomic achievement, responsibility, and accountability.

Despite the funding climate for international agricultural research, ICRISAT's research accomplishments are still highly regarded. In southern Africa, the major donor supporting the joint efforts of ICRISAT and NARS scientists to improve sorghum and pearl millet confirmed its confidence in the impact of this decade-long program by renewing financial support for a further five years. The United States Agency for International Development (USAID) will fund the Sorghum and Millet Improvement Program (SMIP) Phase III, a collaboration among the ten countries of the Southern African Development Community (SADC) and ICRISAT.

In 1992, ICRISAT responded to a request from southern African policymakers to help mitigate the disastrous effects of the worst drought of this century. With generous and timely funding from USAID and the Canadian International Development Agency (CIDA), ICRISAT managed the production of improved varieties of sorghum and pearl millet seed to help small-scale farmers in the area recover from the drought.

This emergency seed production project was remarkably successful. Not only did it contribute to household food security within the region, but it also stimulated the widespread adoption of improved varieties of these two cereals. An impact assessment study showed that farmers benefitted from the improved varieties by more than US$ 4.5 million within a single year. The study also verified farmers' interest in the varieties and provided an evaluation of desirable grain and plant traits. This information is already being used to re-target crop-breeding priorities.

Collaborative trials at Anantapur have been discontinued.

Special project funds, such as that for SMIP Phase III, have become increasingly important as donors place more emphasis on thematic funding. In contrast to the current uncertainty of core funding in the CGIAR, special projects offer relatively secure funds over three to five years.

In a long-term project with the Queensland Department of Primary Industries ICRISAT and Australian scientists worked on improved, low-cost soil management practices for the acidic, infertile, and degraded soils in the Asian, African, and Australian SAT. Designed to encourage sustainable agriculture and rehabilitation of degraded soils, this project began in 1987 and involved a succession of Australian scientists stationed at the ICRISAT Asia Center (IAC). The project was scheduled to conclude in January 1994, but was recently extended to the end of the year.

The African Development Bank is funding a five-year project to improve pigeonpea in eastern and southern Africa. Although it only began in 1991, this project is already having impact. A variety collected in Kenya by ICRISAT scientists was identified as wilt-resistant when grown in a routine nursery at IAC. It was sent to the Malawi national program where it performed well. It was released by the Government and is now widely sought after by farmers. In Kenya, ICRISAT scientists are working with the national program as pigeonpea—a crop often grown by women farmers—gains popularity as both a dry grain and a fresh green vegetable crop for export to Europe.

ICRISAT has hosted Farmers Days for many years at all its locations. Such events enable us to communicate directly with some of the ultimate beneficiaries of our research. At the same time, they provide opportunities for our scientists to learn from the farmers. Over the years women have attended ICRISAT Farmers Days in numbers far fewer than are representative of farming populations. In order to redress the balance, especially as ICRISAT strengthens its efforts to remove gender barriers, Women Farmers Days were held for the first time in three countries in Africa—Malawi, Zimbabwe, and Niger—countries in which women farmers are notably prominent. These were a great success, and we now intend to hold them every year. At IAC, there were two Farmers Days in 1993, one for both men and women, and another exclusively for women.

Women farmers keenly interested in extra-short-duration pigeonpea at an ICRISAT Field Day in Kenya.

ICRISAT continues to be a catalyst in many collaborative initiatives across the CGIAR system.

In 1992, the United Nations Environment Programme estimated that 3.6 billion hectares, or 70% of the world's potentially productive drylands, are currently threatened by desertification. The speed and severity of this degradation have alerted governments and the international community to the urgent need for coordinated action.

The CGIAR has accepted this challenge, and ICRISAT is taking a leadership role. The Desert Margins Initiative relates primarily to sub-Saharan Africa, but also includes the desert margins of Asia. The Initiative will involve several CGIAR centers working together with international, regional, and national institutions to combat desertification, mitigate global climate change, conserve biodiversity, and provide increased food security in these marginal areas. It is designed as an ecoregional initiative in response to the concerns of CGIAR's Technical Advisory Committee (TAC) and the donors. The Director General represented the CGIAR in January 1994 at the third meeting of the Intergovernmental Negotiating Committee for a Convention to Combat Desertification, held at the United Nations headquarters in New York. He described the work of the CGIAR centers as the delegates deliberated the specifics of the international convention.

The Desert Margins Initiative aims to reduce the risk of such severe degradation.

On behalf of the CGIAR, ICRISAT produced a booklet, *Living at the Edge*, which describes the Desert Margins Initiative and the comparative advantages of the partners who are likely to participate. We produced a second publication for the CGIAR, *Challenging Hunger*, which describes the common purpose that links all the centers—eradicating human hunger and poverty, and arresting and reversing natural resource degradation through research. It captures recent changes in the mandate, structure, management, priorities, and strategies of the CGIAR.

ICRISAT participates in several other ecoregional initiatives with its sister centers and other collaborators, and is planning further involvement.

With the International Rice Research Institute (IRRI), we will develop and maintain common databases using the same geographical information systems (GIS) software for all agroecological zones in Asia. The research in this initiative will focus on factors related to degradation of production systems involving the crops of both institutions, with emphasis on nutrient recycling, nutrient depletion, and potential for improving rainfed rice-legume systems.

We plan to continue our sorghum improvement work in Latin America as part of the Savanna Program of the Centro Internacional de Agricultura Tropical (CIAT). ICRISAT will provide the expertise in sorghum genetics, breeding, and disease management, while CIAT will handle the natural resource management research.

ICRISAT is one of four partners in a research program on the development of sustainable resource management systems for the Vertisols of the Ethiopian highlands. Other partners are the International Livestock Centre for Africa (ILCA), Alemaya University of Agriculture, and the Ethiopian Institute of Agricultural Research. The program, funded by the Netherlands, fits in with an initiative led by the International Centre for Research in Agroforestry (ICRAF) on integrated natural resources management research for the highlands of eastern and central Africa.

In a link with the International Institute of Tropical Agriculture (IITA), we are planning joint research on cereal-based production systems in the wetter zones of the semi-arid tropics of West Africa, where legumes are also a major component.

The kabuli chickpea improvement project is a long-term joint effort involving the International Center for Agricultural Research in the Dry Areas (ICARDA) and ICRISAT. The project has had significant success in producing cultivars and genetic stocks with high and stable yields that have been released by national programs. The project also develops segregating populations and materials for NARS crossing programs, and conducts strategic research to support work on germplasm improvement.

The establishment of close working links between ICRISAT/ICARDA and 11 NARS in the West Asia North Africa (WANA) region has allowed us to document and prepare constraint analysis maps using GIS that will be invaluable for exploring opportunities to enhance and stabilize chickpea production and area.

A good crop of pearl millet left to rot after the Maharashtra earthquake.

Legumes are also vital crops throughout India. In October 1993 farmers in one area of the Indian state of Maharashtra were devastated by a severe earthquake. While none of their fields were damaged, their crops were left to rot because there were not enough people to harvest them, and most of the draft animals had been killed. As relief agencies provided adequate food, ICRISAT donated two truckloads of improved chickpea seed so that farmers could once again start to grow their own food.

ICRISAT was recently honored by visits from both the outgoing and incoming Chairmen of the CGIAR. At the end of his two-year tenure as Chairman, V Rajagopalan visited IAC in November 1993, and in February 1994, the new Chairman, I Serageldin, World Bank Vice President for Environmentally Sustainable Development, also visited.

CGIAR Chairman I Serageldin discussing groundnut pests during his visit to IAC.

The new Chairman assumes his responsibilities at a time of crisis in both confidence and funding for the CGIAR. The crisis stems from a misplaced sense of complacency by the international community about the ability of the world to feed itself reliably in the coming decades. Additionally, the international agricultural research centers (IARCs) and their increasingly strategic research agendas are viewed with suspicion by many stakeholders as not being relevant to the solution of the problems of people in degrading environments.

For many, indigenous knowledge and its transfer, along with empowerment of its owners, are seen as the panaceas for environmentally sustainable development and food security. While

A farmer surveys his struggling crops

not doubting the necessity of these elements, it is clear that modern science must also be brought to bear on these twin challenges. Indigenous knowledge and empowerment alone will not suffice in the face of the unprecedented pressure of population and its demands on the natural resource base.

Long-term strategic research on issues related to sustainable natural resource conservation and management and food security cannot be successfully undertaken with the vagaries of annual funding we have experienced in recent years. Funding must be committed for the long term. The dedicated staff of ICRISAT represent a strategic resource which is rapidly eroding in both morale and numbers. The Institute's capacity to be effective in key areas is now being lost because a critical mass no longer exists. This capacity will not be easily restored, and further delays in increasing funding to remedy the problem have high opportunity costs.

The 1994 core funding scenarios we face at the time of writing suggest a figure 12 to 19% below what we received in 1993, which already represented a 17.4% reduction from 1990. If we add the effects of inflation to these percentages, it is easy to see why we describe the situation as a crisis.

The current ad hoc nature of core funding and its uncertainty cause untold damage to programs and performance. It is our obligation to bring to the attention of our stakeholders the serious consequences of such decisions about the funding of ICRISAT. Following the funding reductions already experienced, the likely additional cuts in 1994 will inevitably necessitate yet further wholesale reduction of priority programs.

Eric H Roberts

Eric H Roberts
Chairman, Governing Board

James G Ryan
Director General

ICRISAT has a mandate to improve crops and production systems in an environment that is home to one of every six people on earth—the semi-arid tropics (SAT). Scattered across three continents, most of the 48 developing countries with major areas in the region rank among the poorest in the world.

As the middle of the final decade of the 20th century approaches, poor people living in the SAT continue to struggle. Population growth rates remain high, particularly in the poorer parts of the region. In most countries, cereal production is increasing more slowly than population, and food security is declining.

Africa is likely to be the major victim of this deficit—food production trends are discouraging and the rate of population growth continues to climb. Asia will also suffer shortages. Although the total number of poor in Asia is vastly larger than that in Africa, at least the rate of population growth is dropping in most Asian countries. Asia's population base is so large, however, that further growth will remain a serious problem for several decades. Significant pockets of food insecurity currently exist throughout Asia.

The SAT is characterized by inadequate and uncertain rainfall, large areas of infertile and fragile soils, low capital availability, and weak institutions and infrastructure.

In several countries, high population growth rates are compounded by low agricultural productivity. In many fringe areas, the environment is degrading rapidly as farmers are obliged to cultivate more marginal lands. Per capita food production is also declining in many of these countries.

Farming in the SAT is very hard.

The SAT covers parts of the world where development assistance is crucial. Poverty, food insecurity, and harsh environmental conditions hinder the generation of new technology and make the performance of most technologies highly unstable. Generally low income levels restrict the amount of cash available for investment in new technologies, and food insecurity and low income make farmers reluctant to take risks with new approaches, particularly if they are costly.

Many developing countries in the SAT continue to invest in irrigation regardless of its cost because they recognize the importance of water in increasing and stabilizing food-crop production. Irrigation, however, will not change the SAT's dependence on rainfed agriculture to satisfy human, animal, and industrial needs. Even in India, which has made major strides in irrigation, an estimated 95 million ha (about

Many families are dependent on their groundnut crops.

two-thirds of the cultivated area) must continue to be cultivated under rainfed conditions.

Without adequate improvements in rainfed areas, agricultural growth targets will simply not be met.

As the population across the SAT continues to grow, many developing countries are acutely short of cooking oil. Groundnut in both Asia and Africa will continue to be important in satisfying this growing demand because the crop is so adaptable to a wide range of environments—from the sandy soils of the Sahel to favorable irrigated areas. Groundnut is a critically important protein source for people, while oilseed cake and haulms are important as animal feed. Groundnut production has lagged, however, because prices are low, seed production and distribution are problematic, and farmers have limited access to new cultivars.

While food self-sufficiency for the rainfed SAT population is a laudable objective, the opportunity for income growth in marginal areas will depend largely on markets in better-endowed regions. ICRISAT's mandate crops and associated production systems are tied to rainfed agriculture—making their development particularly challenging. The future also depends on the long-term demand for food, feed, fuel, and commercial products made from these crops.

Urban populations need convenience foods—ICRISAT cereals can provide them.

Africa. There are over 100 million poor people in the zones of sub-Saharan Africa that range from arid to seasonally dry. In 20 of the 29 African countries in the SAT, food intake averages less than 2000 calories per day. The Food and Agriculture Organization of the United Nations (FAO) considers a daily calorie intake of less than 2400 to be an indication of widespread hunger.

In most years, the majority of farming households in the African SAT do not produce enough food to meet the

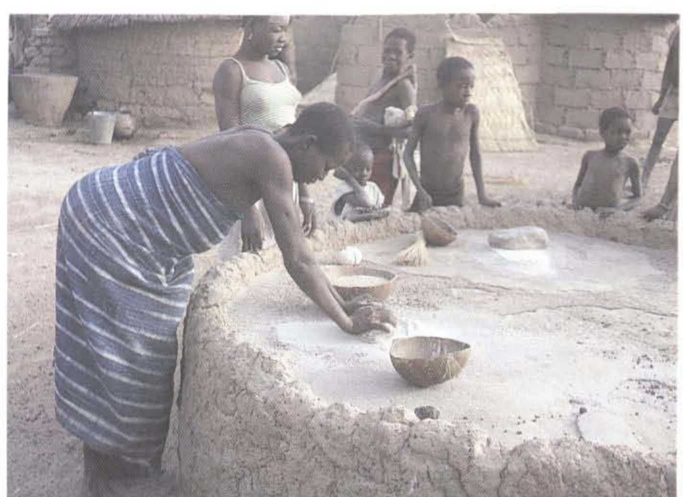
The Semi-Arid Tropics

	Sub-Saharan Africa	South Asia	Latin America
Average daily per capita calorie intake (1989)	2071	2271	2822
Average annual income (US$)	532	662	2483
Countries with average annual income under US$ 400 (1990)	20 of 29	2 of 10	1 of 9
Number of poor (millions) (1985)[1]	180	520	70
Average annual growth rate (%)			
Cereal production (1975–92)	1.95	2.99	1.49
Population (1980–90)	2.68	2.28	1.94
Average annual per capita growth rate (%)			
Sorghum production (1975–92)	1.04	-2.07	-2.03
Pearl millet production (1975–92)	-1.35	-1.74	—
Groundnut production (1975–92)	-3.66	-0.51	-2.67

[1] All agroecological zones

consumption needs of their families, and must rely on purchases, food aid, or both. Many of the households in these countries depend on food aid year after year, and relief programs are ubiquitous.

The use of fertilizers is extremely limited because available cash resources tend to be used to pay school fees and purchase food or other necessities. Research to improve sorghum and pearl millet has generally lagged worldwide because they are not grown as food crops in the developed world where maize and wheat predominate as the cereals of choice. In southern Africa, however, new varieties are starting to be adopted by smallholders, largely as a result of 10 years of collaboration among national agricultural research systems (NARS) and ICRISAT. In western Africa, where environmental constraints are more severe than in southern Africa, increased attention is directed to resource management technologies. Farm resources



Every grain is needed to feed poor families.

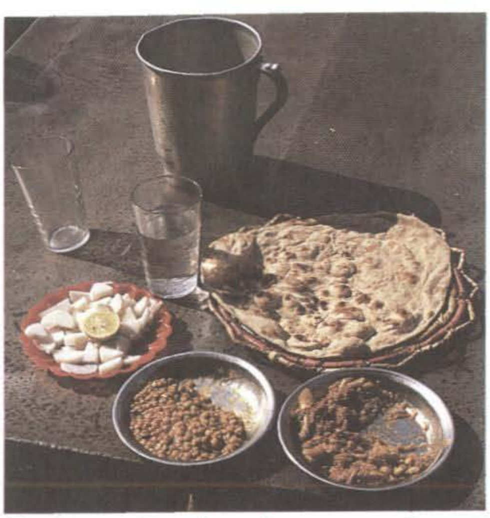
Pearl millet can grow in the harshest environments.

are often so limited, however, that researchers seek low-cost options, even though these generally offer lower yield gains than more costly technologies.

Asia. In general, food production in Asia has fared better than in Africa. Income growth has led to increasing reliance on wheat and rice, but the growth trends for these two cereals are slowing. However, in the poorer rainfed areas of Asia there are still many people who rely on sorghum, millet, chickpea, and pigeonpea.

Although income is rising, poor people still abound—for example, 35% or 520 million people in South Asia live in poverty. The highest percentage of the population in poverty lives in the semi-arid areas. Sorghum and millets have fared poorly during the last three decades relative to other cereal crops in Asia. Although these two coarse grains rank fifth and sixth in cereal production in Asia, their importance is not fully reflected in the figures.

Often referred to as 'poor people's crops', they are grown and consumed mainly by the rural poor. In Asia, small-scale farmers devote a higher proportion of their land to sorghum and millet than do large-scale farmers.



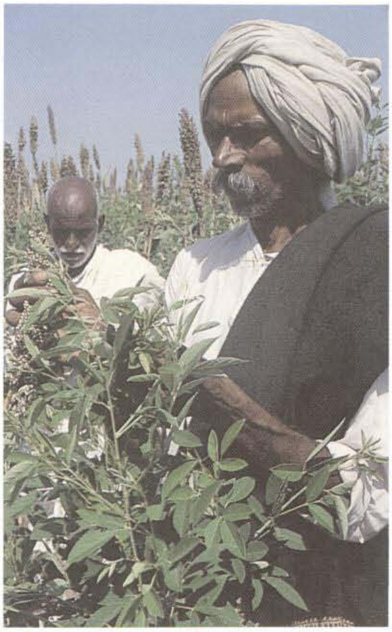
Vegetarian diets depend on our mandate pulses for protein.

Sorghum and millet are largely consumed in the regions where they are grown, often in areas where few other economically viable alternatives exist. In some areas, sorghum and millet are grown commercially to supply grain and stover for livestock, but they are the staple foods of the poorest of the poor. The reduced competitiveness of these two cereals—the result of low producer prices—has pushed these crops onto increasingly marginal lands, making future productivity growth more difficult.

The poor also depend on pulses such as chickpea and pigeonpea to help meet their nutritional requirements. If adopted, new production technologies developed by ICRISAT and its partners can significantly increase productivity, lower per-unit production costs, and ultimately ensure lower market prices. Legumes—an important protein source—will increasingly contribute to the sustainability of global production systems, primarily because they fix atmospheric nitrogen and thus make a positive contribution to the soil nutrient balance.

Although chickpea and pigeonpea account for only 17% of the world production of pulses, these figures understate the importance of these crops in Asia, the main region of production. Even though chickpea is grown throughout the world, the bulk of it is produced and consumed in South Asia and increasingly in West Asia, North Africa, the Middle East, and some Mediterranean countries, often in semi-arid environments. The average annual growth rate of production is slow at 1.9%, and yield has risen only 0.6% annually.

Pigeonpea production is more concentrated—more than 90% of the crop's world area and production are in India, but it is also cultivated elsewhere in Asia, eastern Africa, and Central America. In India, cultivated area and production growth exceeded 2% per year from 1970 to 1990. Yield growth rates were stagnant, however, perhaps because pigeonpea is not a primary crop. It is usually relegated to marginal soils and intercropped with sorghum and cotton. In some areas, however, farmers are now growing more sole crops of pigeonpea, which is gaining status as a cash crop.



Farmers on the Deccan Plateau intercrop sorghum and pigeonpea.

Latin America. Sorghum is by far the most important of the ICRISAT mandate crops grown in Latin America. Of the 5.4 million t produced annually in Central America and the Caribbean (Mexico alone grows 89% of this total), most is grown on large farms to supply the stock feed and brewing industries. Large-scale farmers tend to rely on commercial sorghum hybrids, most of which are bred and distributed by private-sector seed agencies. The grain produced by these hybrids is not preferred for food.

Small-scale farmers seek access to cultivars incorporating drought resistance with good food quality and high productivity for their low-input monocropping and intercropping systems. They prefer cultivars whose seed they can retain to sow in the following season. Production systems are highly variable—management techniques often vary depending on topography and rainfall reliability, thus management may be intensive, but purchased inputs are usually minimal.

In the Central American and Caribbean region, the most important food crops are maize, beans, rice, and sorghum. Except in Mexico, sorghum is usually intercropped with maize, beans, and cassava, and about 64% of production is used for human food. Sorghum flour is often used to 'extend' maize. Despite the dominance of large-scale


Marginal lands cannot produce good crops.

sorghum production in the region, the largest number of producers remains small-scale farmers who grow this grain for food—about 400,000 t of sorghum on small farms of 5 ha or less on a total 450,000 ha. Average yield is 0.9 t/ha.

Most of the 4 million t of sorghum grown in South America is hybrids grown for feed (grain yields average about 2.7 t/ha). Commercial sorghum hybrids for feed grain production predominate in this region. Only in Brazil, Paraguay, and Uruguay is some sorghum used for human consumption to extend wheat flour in bread.

Future Production Increases. Throughout history, the main source of agricultural growth has been expansion of the area cultivated. Except in a handful of countries, this has now reached its limits. Already, cropping has extended to land too dry or too barren to give reliable yields. As farmers scramble for more land in mountainous regions, they may cultivate steep slopes without taking adequate precautions to prevent erosion.

The pressures on rainfed agricultural land in the SAT are increasing due to increased demands for food and feed. The natural resources (soil, water, nutrients) remain the same, but improved management is essential if we are to reverse the degradation of the natural resource base and develop production systems that sustain farming communities.


It is hard to protect the environment when firewood must be found to cook food.

Quite simply, ICRISAT's preoccupation with natural resources management in the SAT is a fundamental strength and an essential investment to achieve sustained increases in production in SAT environments.

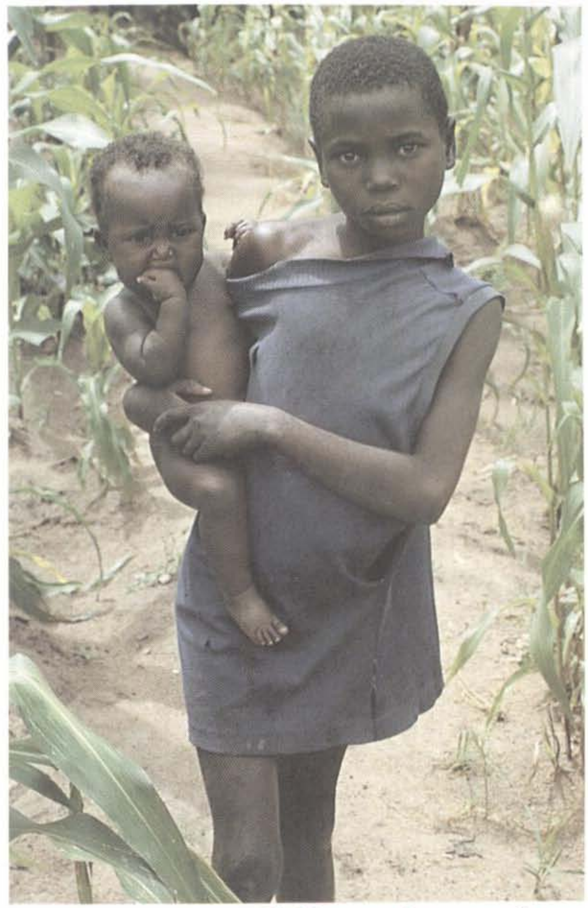
Future growth of agricultural output must come from increased productivity per unit of land. Research has been the major source of such growth in the past 50 years, a pattern which must continue in the future.

ICRISAT is called upon to do its part in feeding and helping to generate new sources of income for the 90 million people born each year in developing countries. The challenge for agricultural research has become far more complicated than the 'food first' imperatives of the 1960s and 1970s that gave rise to the Green Revolution.

The five related problems of food production, malnutrition, poverty, population growth, and the environment are more acute now than they were 20 years ago when ICRISAT was founded. Today, it seems that concern for the environment overshadows the other four equally salient elements that are all inextricably related.

Poverty limits opportunities for protecting and enhancing the environment—poor people have few options but to exploit the natural resource base in order to strive for food security, and sometimes even to survive.

Poverty also hinders efforts to manage population growth because for poor people, children represent additional sources of income. Broadly based activities to alleviate poverty are the answer—new technologies must be found to improve and sustain agriculture.



Children need a secure future.

The links between higher productivity in agriculture and general economic growth are direct and real. Productive farmers reduce their costs, earn higher incomes, enhance their own well being—and thus may be more likely to invest in protecting the environment. Environmental conservation and increased food production are complementary because there must be a minimum level of food security before farmers will consider major investments in longer-term conservation measures.

ICRISAT has a proud history of more than two decades of helping resource-poor farmers. At the start of its third decade, the newly reorganized and revitalized ICRISAT stands ready to deal with the continuing environmental challenges of the semi-arid tropics.

In June 1992, world leaders convened the United Nations Conference on Environment and Development—the 'Earth Summit'—in Rio de Janeiro. This group developed Agenda 21—a statement of goals and a list of strategies and actions aimed at 'reconciling the world's economic activities with the need to protect the planet and ensure a sustainable future for all people.'

Just as the world's natural environment is changing, so is ICRISAT's external environment. In reponse to these changes, we developed a carefully prepared Medium Term Plan (MTP), which spells out in detail how we will attain the goals laid out earlier in our strategic plan for the last decade of this century. Clear parallels are apparent between ICRISAT's objectives as identified in our MTP and those agreed on by the Earth Summit delegates in Rio. In fact, 80% of the themes in the ICRISAT research portfolio directly address one or more of the priorities identified in Agenda 21.

External Environment. Since it was founded in 1971, the CGIAR has paid for itself many times over, achieving a remarkable record of success in food production, economic development, conservation of genetic resources, and environmental protection throughout the developing world. As the world population continues to grow, so does the need to feed it—along with the need to continue research on producing more food from dwindling agricultural land without further damaging the fragile environment.

The donors' sphere has become increasingly complex as they grapple with such issues as the needs of the emerging nations of the former Soviet Union and Eastern Europe, along with those of millions of refugees, many of them camped in countries of the semi-arid tropics which can ill afford to support them. It is vital, however, that these issues do not distract the world community from its commitment to invest in long-term agricultural research.

The CGIAR has taken a significant step to manage its resources more effectively at a time of budgetary contraction—a strengthened focus on the issues of natural resource management and sustainability. These complement traditional contributions to food security through crop improvement, institution building, training, and policy research.

ICRISAT also realizes that to ensure the successful adoption of its technologies, intended recipients should be involved from inception to implementation. Research results and technology produced in a metaphoric vacuum behave differently from those in an actual vacuum—rather than sucking in everything around, they simply stagnate. National research and extension organizations and non-governmental organizations (NGOs) provide the crucial link to the ultimate targets of our research, the poor farmers of the semi-arid tropics (SAT). If we fail to consider this crucial stepping stone to development, our work has little value.

Measuring Impact. Increasingly, our donors need to see the results of their investment and to appreciate what their money has achieved.

As a result, economists and other social scientists are increasingly being asked to quantify the impact of the international agricultural research centers (IARCs). Systematic and comprehensive impact assessment of ICRISAT-generated technologies is important for three basic reasons.

- Results from such an assessment provide a basis for setting future priorities among research options
- Researchers are provided with feedback regarding our partners' needs
- It provides a basis for satisfying our donors' needs for accountability of their research investments in us

Recognizing the importance of including impact assessment as a basic component of each research project, ICRISAT held the first of a planned series of workshops on research evaluation and impact assessment in December 1993.

Medium Term Plan. ICRISAT's MTP was formulated in the light of the system-wide issues affecting the CGIAR. In addition, our most recent External Program and Management Review recommended increases in interdisciplinary teamwork and research coherence across locations, as well as highlighting the need to demonstrate the impact of our research. The MTP is a compilation of prioritized research themes designed to address the major biotic, abiotic, and socioeconomic constraints to sustainable growth in agricultural productivity in the SAT.

The methodology used in the development of the MTP was innovative and highly analytical, with the entire Institute contributing to the data and judgements on which the plan was based. Based on detailed analysis of the economic consequences of the various constraints affecting ICRISAT mandate crops and the SAT environment, and following considerable discussion, a total of 92 potential research themes were identified as components of ICRISAT's core-funded research portfolio. These 92 themes were ranked using four criteria.

- Efficiency—as measured by a net benefit:cost ratio derived from the estimated economic value of success in the conduct of the research, the likelihood of success, the potential for spillover benefits, research and adoption lags, and the influence of markets

- Equity—as measured by two variables; the number of absolutely poor people in the research domain where the constraints were judged to be serious, and the number of female illiterates in the same domain
- Internationality—as measured by a mathemetical technique which ranked the themes according to the extent of their international impact
- Sustainability—as measured by the likely contribution to the conservation or enhancement of the natural resource base if new technologies are adopted by target recipients

Each of these four criteria was given equal weight in the computation of a composite index used to provide an overall ranking of all 92 themes. By examining this ranked list, themes which might be lost through insufficient funding are immediately apparent, together with their potentially lost benefit streams.

This methodology also led to a plan emphasizing a thematic approach to research, incorporating interdisciplinary and collaborative teams whose work is focused around production systems. The need to coordinate research across regions and disciplines led to the concept of matrix management as a means of guiding project-based research on production systems. Furthermore, the data and judgements collected through the analytical process used in the development of the MTP provide clear milestones for monitoring and evaluating the progress of research, and also provide a basis for demonstrating ultimate impact.

Production Systems. The reorganized ICRISAT includes an emphasis on 29 production systems, allowing us to focus on our mandate commodities in realistic situations, and to identify specific researchable problems and the areas in which to assess their impact. Production systems are defined by four descriptors.

- Geography
- Environmental resources
- Key elements in the major farming systems (including commodity production trends and key socioeconomic variables)
- Important issues or constraints to improving productivity and sustainability

The complete description of the production systems is complicated. It makes use of computer-based geographic information systems (GIS) to identify and quantify the coexistence of climate, soil, social, and other data that influence agricultural development.

Proposed

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 Plain.*

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

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.*

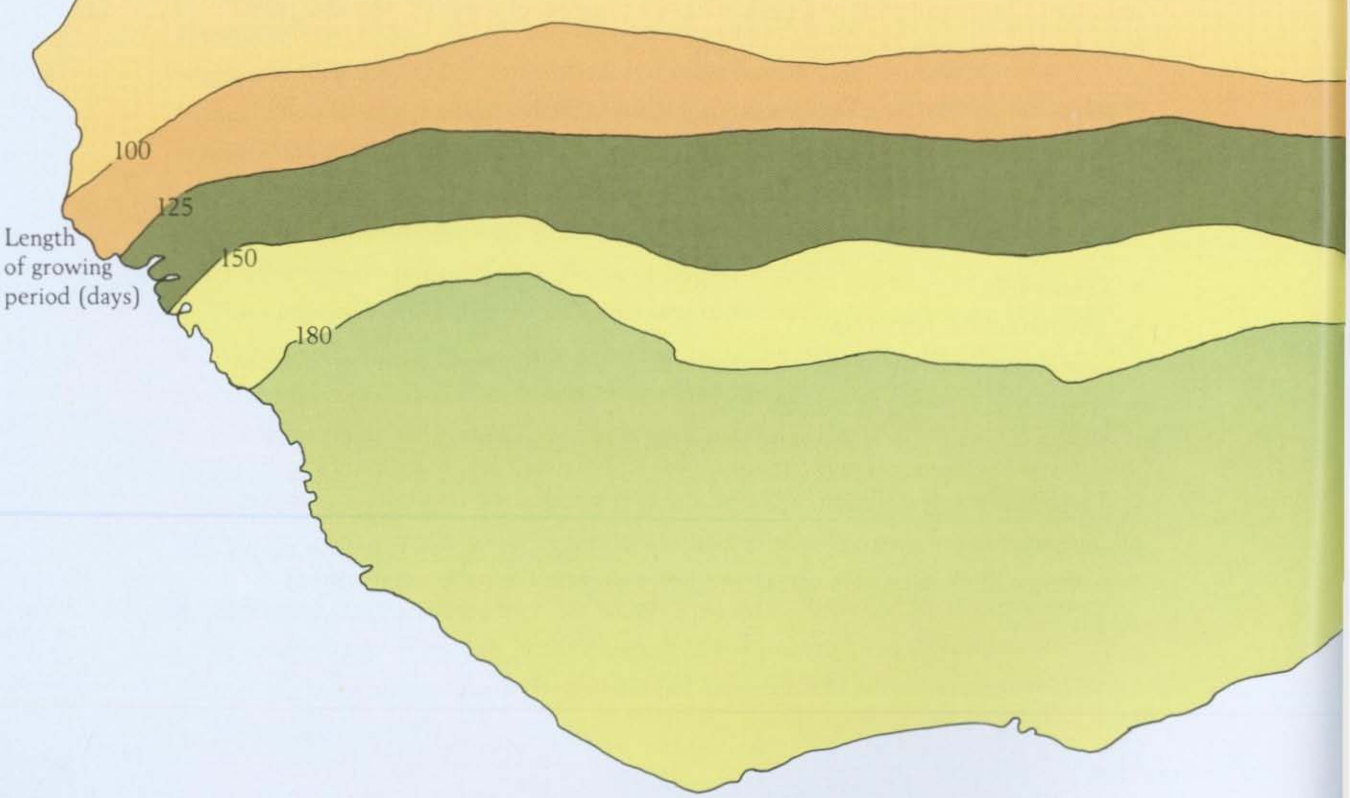
12 Subtropical, intermediate elevation, winter rainfall and rainfed, wheat-based. *West Asia and North Africa.*

West Africa

13 Transition zone from arid rangeland to short-season (less than 100 days), rainfed, millet/cowpea/livestock. *Sahelian Zone.*

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.*



Production Systems

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.*

Southern and Eastern Africa

19 Lowland, rainfed, short-season (less than 100 days), sorghum/ millet/rangeland. *Northern parts of eastern Africa, parts of southern Africa.*

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.*

Latin America

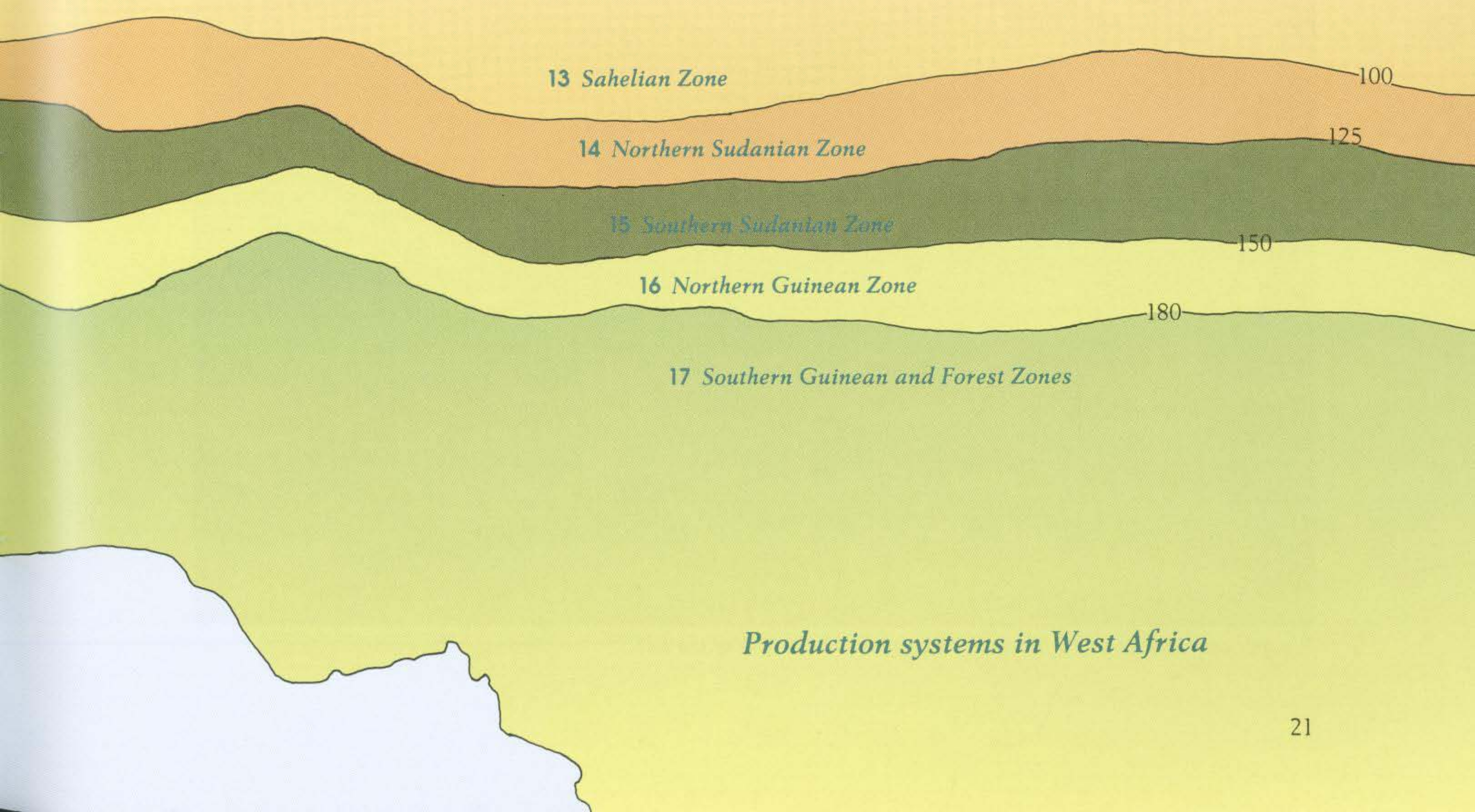
25 Tropical, upland, rainfed, maize/sorghum intercropping. *Central America and Hispaniola.*

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 systems in West Africa

We will continue to work for food security for the people of the SAT.

We continue to hold global responsibility for our six mandate crops, while there are clear advantages to using production systems to organize research.

- While maintaining our commitment to our mandate crops, interdisciplinary teams can be provided with identifiable objectives to focus on real problems, exploiting the synergism of genetic, management, and socioeconomic research
- A concrete basis for collaboration can be established with our partners in the national programs, all of whom have mandates that focus primarily on applied research for their nationally or regionally important production systems
- Ecoregional initiatives or research consortia that embrace NARS and IARCs and also focus on conservation and management of natural resources that interest donors are clearly delineated
- The direct impact of research on the target production system, and spillover effects in related production systems or geographic areas, can be more easily assessed
- A mechanism that helps management summarize research needs to plan for the required human and financial resources is provided
- Scientifically and geographically diverse research work can be described in a logical, cogent way, thus presenting a coherent picture to stakeholders
- Research packages can be more easily identified for donors who are emphasizing thematic funding and less reliance on unrestricted core funding of whole institutions

As ICRISAT's work moves to a focus on these production systems with more emphasis on interdisciplinary research, fundamental changes have taken place.

- Primary and secondary research domains of the SAT were specified for the research themes. Thus there was an explicit ecoregional basis to the entire MTP
- The current operationalization of the MTP involves organization of the research themes into research projects targeting the priority needs of specific production systems identified as having particular regional importance in the SAT.
- The projects clearly group according to their target production systems, and the production systems can be aggregated into the TAC Regional Agroecological Zones
- Therefore the MTP and the resulting projects involve an explicit ecoregional approach to research, through identification of major production systems regionally in the SAT, and targeting priority outcomes for those systems.

New Organization. Under the new structure, ICRISAT's research will be packaged with the project—not the program—as the basic unit of operation and management.

A portfolio of global research projects will be established, defined in relation to the priority needs and research opportunities within a set of specific production systems identified in the four major regions of the SAT—Asia, Eastern and Southern Africa, Western and Central Africa, and Latin America and the Caribbean. These production systems will act to integrate and target our research, and to link ICRISAT to national programs and regional networks.

Each project will have a designated team and clearly defined objectives and milestones. The team will be accountable for the development, conduct, management, resource utilization, reporting, and impact assessment of the project.

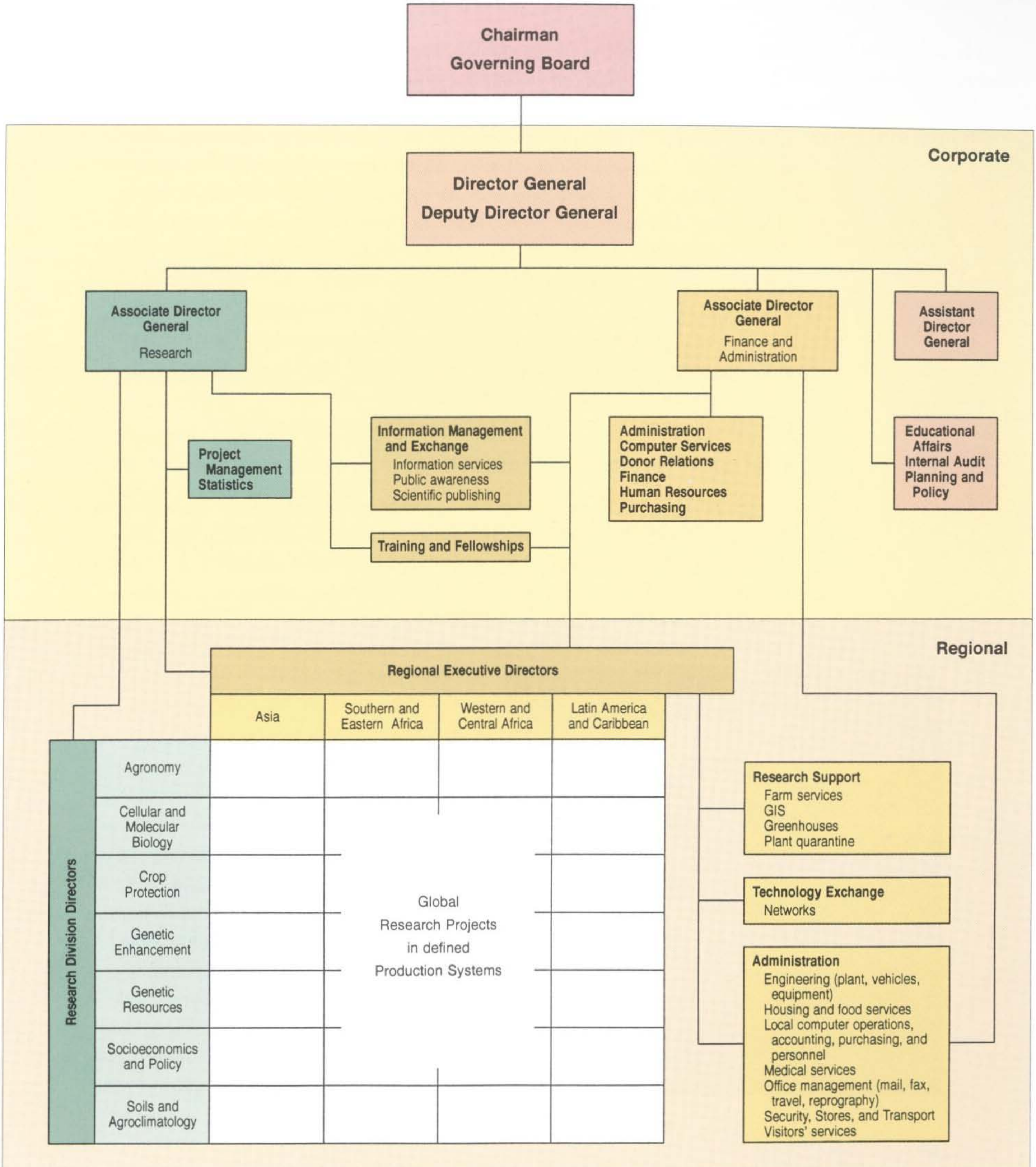
ICRISAT's human and financial resources will be more efficiently used as the responsibility for use of these and the success of each project is devolved to the members of project teams.

Many ICRISAT staff felt that under our previous, predominantly hierarchical management system, accountability was vested in limited numbers of people and did not encourage teamwork. This tended to inhibit productivity and initiative. The new organizational system is designed to ensure that ICRISAT staff are accountable for their work. Once the responsibility for conducting a project, or part of a project, has devolved to a staff member, that person carries the responsibility and authority for the relevant activities.

To facilitate the definition, development, management, and conduct of projects, an organizational framework employing a tandem matrix was developed. There are two dimensions to the matrix. The horizontal axis of the matrix includes four geographic regions, each of which has an Executive Director responsible for the management and support of research focused on the agreed production systems within that region. The former ICRISAT Center now comprises the Corporate Office and the ICRISAT Asia Center (IAC).

The geographic regions are complemented by seven disciplinary research divisions on the vertical axis of the matrix, each led by a Research Division Director. These divisions have global responsibilities. While primarily involved in research planning, coordination, and scientific quality control, the Research Division Directors remain active research scientists.

The axes of the matrix are designed to emphasize shared responsibilities, goals, and outcomes through development and delivery of a relevant global research project portfolio. In contrast to the previous hierarchy, management of research and resources is now devolved to project teams and leaders.


Chairman
Governing Board
Corporate
Director General
Deputy Director General
Associate Director General
Research
Associate Director General
Finance and Administration
Assistant Director General
Project Management Statistics
Information Management and Exchange
Information services
Public awareness
Scientific publishing
Administration
Computer Services
Donor Relations
Finance
Human Resources
Purchasing
Educational Affairs
Internal Audit
Planning and Policy
Training and Fellowships
Regional
Regional Executive Directors
Asia
Southern and Eastern Africa
Western and Central Africa
Latin America and Caribbean
Research Division Directors
Agronomy
Cellular and Molecular Biology
Crop Protection
Genetic Enhancement
Genetic Resources
Socioeconomics and Policy
Soils and Agroclimatology
Global Research Projects in defined Production Systems
Research Support
Farm services
GIS
Greenhouses
Plant quarantine
Technology Exchange
Networks
Administration
Engineering (plant, vehicles, equipment)
Housing and food services
Local computer operations, accounting, purchasing, and personnel
Medical services
Office management (mail, fax, travel, reprography)
Security, Stores, and Transport
Visitors' services

To ensure coordination throughout the research portfolio, with our NARS collaborators, and through various regional networks, active research scientists have been designated as Crop Coordinators for specific mandate crops in each region. In recognition of the changing external environment, the Deputy Director General's responsibilities include ensuring effective and harmonious relationships between ICRISAT and NARS worldwide, and with our sister centers within the CGIAR system.

ICRISAT's Executive Directors and Research Division Directors are spread across two continents. The Associate Director General for Research will also act as Executive Director for the Latin America and Caribbean Region because it is a small program. Such a management structure—indeed, the wide-ranging debate during formulation of the MTP—would not have been possible without the electronic mail and computer networking capabilities developed at the Institute during the last 10 years. Scientists and administrators routinely consult each other and their collaborators using this rapid and cost-effective means of communication.

What Hasn't Changed. Although ICRISAT is currently implementing a major reorganization and restructuring, many of our basic goals and ideals have not changed.

- Our global mandate to improve six staple food crops that sustain the world's poorest people is still paramount. We continue to seek ways to manage the fragile natural resources of the semi-arid tropics
- Our partners are still the national programs of the countries in which these people live and farm

- The targets of our work are still the farmers and consumers of these countries
- We are committed to removing gender barriers
- Our work is still important to hundreds of millions of people throughout the world

After 20 years, it was time for ICRISAT to take a hard look at itself and to revitalize its staff and work. The opportunities afforded by both the MTP and the fundamental strategic review of our role, programs, and organization gave us the chance to sow the seeds of future success. Their germination and growth depend not only on ICRISAT, but also on its partners, collaborators, and donors.

This section provides highlights of recent happenings and achievements of ICRISAT. It is not intended to provide a full historical coverage. Rather, this sample of events and accomplishments is selected to present an effective, and reasonably comprehensive, digest of ICRISAT's work during the period of this report. Annual Reports that provide more detailed descriptions of specific scientific achievements are available from regional headquarters.

Geographical Information Systems — GIS

Information is power—and for agricultural scientists, understanding the complex relationships among all the elements of an agroecosystem and its associated socioeconomic factors is now easier—thanks to the use of advanced computer software.

This software includes geographical information systems (GIS) that are helping ICRISAT researchers to understand the nature of the limited resources of the SAT.

Environments Under the Microscope. The environment of a crop, land use, or farming system has physical, chemical, biological, and socioeconomic aspects. The nature of these variables varies across time and space, which means that particular crop cultivars and management methods are optimum in different places and at different times. Agricultural scientists want to understand the complex interactions among these variables to provide more effective management of the crop or land system.

The GIS helps scientists to simultaneously examine a whole range of temporal issues, such as changes in land use, soil conditions, use of inputs, access to markets, etc. Output from the GIS helps them understand how these changes occur, and the conditions that support the ones which benefit farmers and consumers.

Analysis of the complex interrelationships among soil, climatic, and socioeconomic factors is a daunting task. Mapping layers of data by GIS can help locate agroecological groupings which reflect major constraints to production. During 1993, ICRISAT scientists superimposed length of growing period (LGP) zones on the FAO/United Nations Educational, Scientific, and Cultural Organization (Unesco) soil map of the West African SAT, delineated the principal LGP and soil units in this area, and calculated the areas of these units.

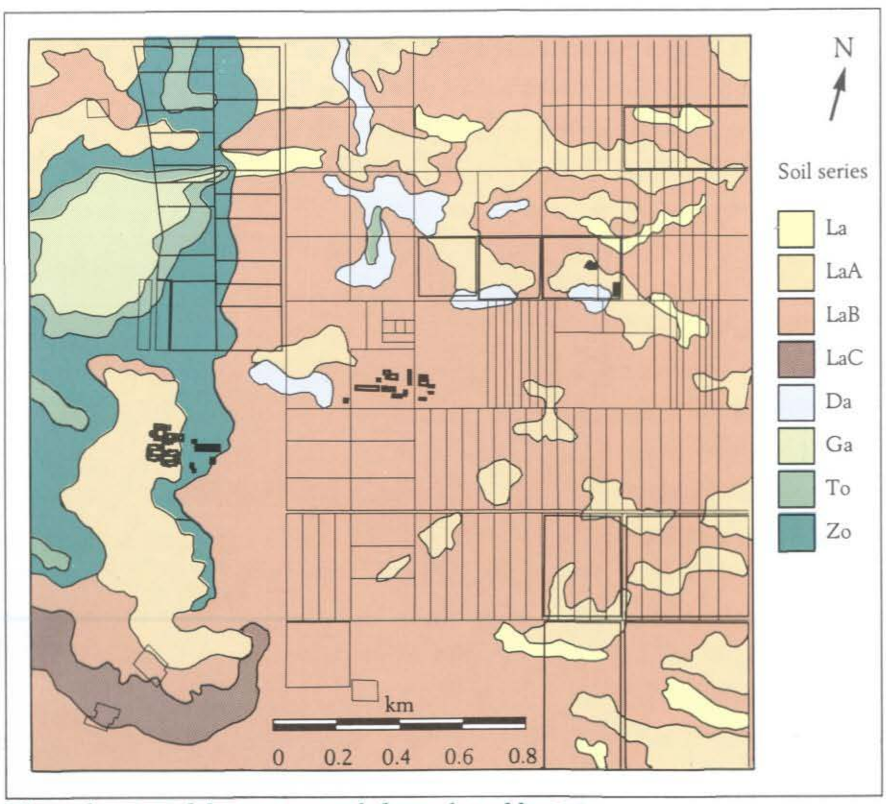
Manipulation of these data using GIS will help identify areas where proven, improved practices are most likely to succeed, and where and on what crops limited inputs should be applied to achieve maximum returns. These questions can only be answered by characterizing environments and analyzing data, and for such purposes is a powerful addition to the agricultural scientist's research kit. Data manipulated by the GIS also provide valuable input for models.

Scientists are mapping such data as soil type, LGP, area and production of crops, population, and value of production to identify primary agroecological zones. The expected payoff from research interventions in these zones can be calculated by using computer-mapped overlays of constraints to yield and probability of success—both biotic (such as insect pests, diseases, and weeds) and abiotic (drought or low soil fertility, for example).

Integrating measures of poverty with population data helps address questions of equity and gender issues in different zones. The results of this research—aimed at planners and policymakers in national and regional agencies—will be easily understood, color-coded maps showing the potential for success of multiple strategies in different agroecological zones in the SAT.

Managing the Research Station. Access to and manipulation of land-related information is a crucial element of managing a research station. The use of GIS helps integrate all phases of field-oriented research, from experiment design to data analysis.

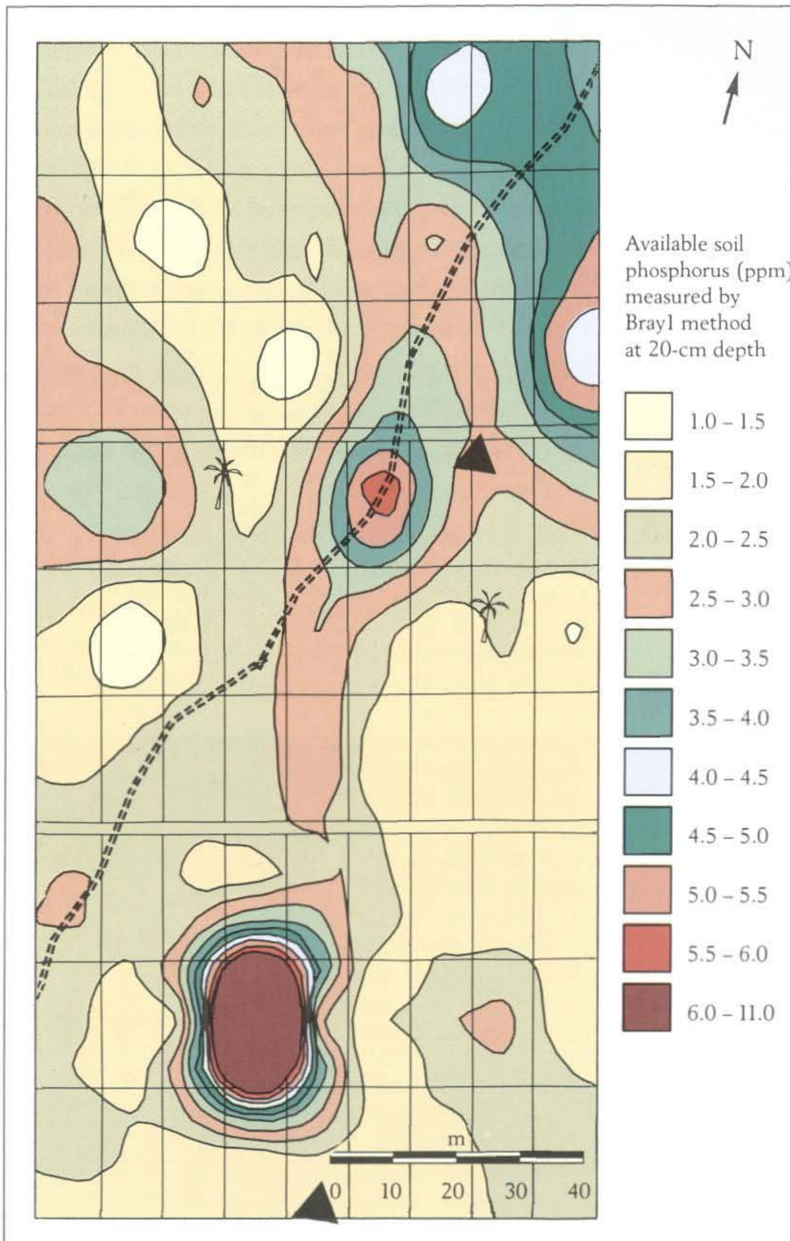
The ICRISAT Sahelian Center (ISC)'s 500-ha research station is managed using a GIS, and a database that includes the entire land history since the station was established in 1982. Beginning in 1988, the ICRISAT Asia Center (IAC) adopted the same GIS. The research station in India is almost three times as large as the one in Niger, and has a cropping history that



The soil series of the ISC research farm plotted by GIS.

dates back to 1972. Data for IAC back to 1981 have been entered into the system, and eventually the entire land-use history will be available on computer.

Preparing maps of land usage at ICRISAT's research stations used to be a cumbersome and time-consuming process, with the added frustration that by the time a map was complete, it was already out of date. Use of GIS technology eliminates this problem—maps can be updated on demand. In addition to producing basic land-use maps, the GIS manipulates and packages the available information on land use in a manner which helps plan and interpret research results.



Soil phosphorus plotted by GIS for a crop residue experiment in a field at ISC.

- Improves land allocation based on research requirements, land and field history, and resource characteristics
- Improves the quality of field history data for planning experiments and analyses
- Improves the monitoring and follow-up of land-use patterns
- Helps plan station activities and increases their efficiency

Data from the GIS are helpful to scientists when choosing land for an experiment. Data from a soil survey on a 20 × 20 m grid were entered into the GIS database at ISC, and are now of great help in deciding the treatment allocation according to specific fertility needs. For example, if a researcher is planning a trial to study the effects of phosphorus on a crop, then the GIS can show all the available fields with a uniformly low level of P and an appropriate cropping history. The system can superimpose soil type, fertility, and cropping pattern on a single map.

Data from the GIS are used to schedule all station operations such as sowing, cultivation, irrigation, fertilizer application, and plant protection (at specified threshold levels). As more detailed descriptive data become available in the future, they will be added to the system in units smaller than a single field; for example, the nematode population density within an individual trial.

By transferring GIS data sets between IAC and ISC, researchers who are conducting trials at both locations will have access to much more detailed field histories at both locations.

Improving Fodder. ICRISAT is collaborating with the Indo-Swiss Project Andhra (ISPA), a bilateral effort of the Indian state of Andhra Pradesh and the Swiss Development Cooperation, to improve cattle numbers, health, and milk production by increasing the fodder supply. GIS is an important tool in this work.

ICRISAT's work with ISPA is helping produce fodder that can generate income for farmers in Andhra Pradesh.

After three years of on-farm studies in Andhra Pradesh (an area slightly larger than the UK) scientists identified two dual-purpose fodder/grain sorghum genotypes which were well-adapted and acceptable to farmers. Over 250 farmers now grow these varieties.

Currently, ISPA is assembling a livestock database and ICRISAT scientists are creating a second database which covers soils, crops, and rainfall. Both databases use mandal-level information. Mandals are relatively small administrative units within a state, and there are 1063 in Andhra Pradesh. When the two databases are merged, it will be possible to identify areas where farmers can expect a good payoff from growing these fodder varieties for two reasons—the cropping environment is appropriate, and they are close enough to urban centers that can consume the extra milk.

Using the power of GIS to extract information from the merged database, the collaborators can use maps to examine the entire production system and plan a cohesive approach to expanding fodder and dairy production in Andhra Pradesh. This information-processing capability has diverse potential.

- For the scientist, identification of primary constraints to improved production as targets for research
- For extension workers and agro-industry, a clear focus for technology exchange and investment in services
- For policymakers, a basis for decisions about infrastructure development within the region.

Managing Soil and Water

Water is a worry for farmers all over the world. In some environments the worry may be too much water, but for farmers in the SAT the problem is usually the opposite—not enough water, or not enough water at a time when their crops need it. ICRISAT scientists are developing technologies to help farmers use the water available to them in the most efficient and economical manner.

In West Africa millet crops are dependent on scarce rainfall.

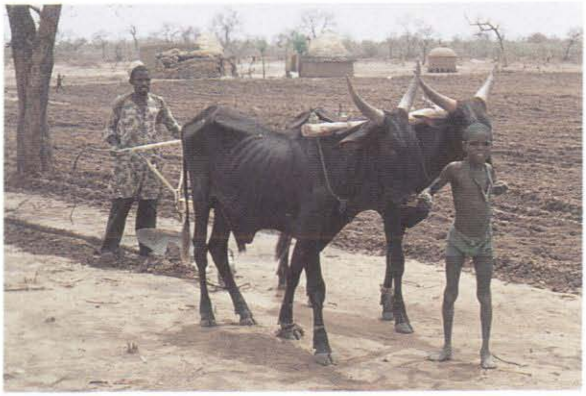
New Techniques for West Africa. Africa contains the largest land area within the SAT, over 217 million ha, an area equivalent to almost 25% of the USA.

Despite investments in irrigation by many African countries, domestic food and feed production will continue to rely largely on rainfed farming.

Understanding how rainfall affects a cropping system is of particular importance in West Africa because rain is undependable and the soils are poor and have low water-holding capacities. It is necessary, therefore, to quantify how efficiently a crop uses water to produce biomass and food, and the different ways in which rainfall escapes use by a crop. In the sandy soils of West Africa where pearl millet is grown, rainfall is often 'lost' to crops by drainage beyond the root zone. In some years, drainage losses can be extremely high. Also, relatively small changes in soil wetness or texture can drastically change drainage so that it is difficult to extrapolate a measure of drainage from one location to another, even within the same field.

On sandy Sahelian soils pearl millet is often intercropped with cowpea.

Because high labor costs and expensive instrumentation have inhibited study of this problem at ISC, scientists there have developed a simplified method of calculating root zone drainage from measured profiles of soil water. This new mathematical technique has been successfully tested against classic, expensive methods, and should therefore save thousands of dollars in labor and equipment, and countless hours of field work. And because the technique is site-specific, it also greatly increases the accuracy with which scientists can calculate root zone drainage, and therefore crop water use.



Draft animals need adequate fodder if they are to provide traction power for tillage operations.

ISC scientists used their new technique to determine the effects of management practices on crop water use in mono-cropped pearl millet and in a pearl millet/cowpea intercrop.

For the intercrop, they compared the effects of postharvest tillage and pre-sowing tillage on water use. The scheduling of tillage operations is an important consideration because draft animals are in much better physical condition immediately after harvest when more feed is available, than they are before sowing.

Scientists found that although postharvest tillage conserved a small amount of water compared to pre-sowing tillage and no tillage at all, probably due to weed control, yields were slightly lower. Seedling establishment was better after pre-sowing tillage, thereby improving water use.

The simplified method of calculating root zone drainage was also used to assess the effects of climate, management, spacing, fertilizer application, and genotype selection on yield and water use in mono-cropped pearl millet production systems in four contrasting rainfall years.

This study enabled scientists to identify limiting factors to mono-cropped pearl millet production in West Africa, and to develop models to predict yield from water use under various levels of management and differing degrees of aridity. At moderate levels of fertility and sowing densities, crop water supply was not limiting during any but the very driest year (about 250 mm rainfall). Water-use efficiency (and therefore yield) increased by approximately 450% compared to that in low-input fields, without any increased risk. At higher fertility levels and sowing densities, however, additional risk was introduced. The implications of these results on management of these West African farming systems are quite fundamental, with major potential impact on food and food security.

Scientists have long known that tillage, choice of genotype, fertility level, and plant spacing all affect yield. But this new technique for estimating root zone drainage has allowed ISC researchers to quantify the effects of these factors on crop water use with much higher accuracy. Understanding these complex relationships will aid ICRISAT and its NARS partners in helping farmers to manage undependable water supplies, thereby increasing their pearl millet yields.

When all the factors are right, pearl millet can produce an excellent crop—even in the Sahel.

Water Harvesting in India. Distribution of rainfall during a cropping season is often far more important than the total amount of rainfall. Frequent short-term dry spells or an early end to the monsoon season are quite common in dryland areas.

For many years, ICRISAT scientists have been studying water harvesting for supplemental irrigation—the collection of excess runoff water from a catchment area for use at a time determined by the farmer. Harvesting runoff water for supplemental irrigation is often a highly effective way to increase and stabilize crop production on the fragile soils of the SAT.


Tanks save precious water.

The early work focused on the concept that every drop of rain falling on a catchment area should be conserved, and therefore it was necessary to dig large water storage tanks to capture most of the excess runoff water, even in years of extremely good rains. The problem with this concept, however, was that in most years tanks were not full, and only about 15 to 30% of their capacity was used. Thus the cost per unit of water stored and available for irrigation was very high because it is expensive to dig large tanks.

In on-station trials at three locations in India during the last two years, ICRISAT scientists have been collaborating with the Central Research Institute for Dryland Agriculture (CRIDA) to investigate a different concept in water harvesting. The goal is to make water harvesting technology more cost-effective and affordable to farmers by excavating a relatively small water storage tank for a given catchment size. This approach reduces the tank size so that in most years the tank is full, but use of its capacity is high. Smaller tanks are not large enough to conserve 100% of the excess runoff from the catchment, but the system is more economical and probably will be more adoptable by farmers because the cost per unit of stored water for irrigation is lower.

One of the advantages of working with an organization such as CRIDA is that in addition to having several research stations located in different agroclimatic zones which can potentially adopt this water harvesting technology, it has established links and networks with other Indian Council of Agricultural Research (ICAR) organizations whose clients could also adopt this technology.

Initial trial results have been favorable—a cotton crop irrigated once during the season yielded 50 to 60% more than a nonirrigated control. Scientists are working initially with a highly commercial crop—which is often grown in rotation with sorghum—that responds well to irrigation to develop the technology, and will then adapt it to food crops. Data from these experiments are being used to construct a model which can be used to transfer the concept to other locations.

Removing Gender Barriers


Women must work in the fields and care for their families.

Women provide much of the farm labor throughout the SAT. They are also homemakers who use all of ICRISAT's mandate crops as staple foods for their families, as well as pigeonpea for firewood, and groundnut haulms and cereal stover for fodder. In southern and eastern Africa, women are the predominant farmers.

Women contribute significantly to agriculture in the SAT, and to be truly effective, strategies to improve production systems and crops must involve them directly.

ICRISAT is conscious of the several considerable barriers to women's full participation in agricultural development. Through its policies, research activities, and training, ICRISAT encourages removal of these obstacles. Holding Farmers Days exclusively for women is just one demonstration of the Institute's commitment to removing gender barriers.

Our gender program began in earnest in late 1991 when an economist was assigned to incorporate gender analysis into ICRISAT's research. We focus on the impact of new agricultural technologies on both men and women, and on their differing roles in the practical implementation of these technologies. Proactive gender analysis is a feature of the MTP, which will have its focal point in the Socioeconomics and Policy Division. However, all scientists will be expected to factor an appropriate gender perspective into the planning and conduct of their research.

As one example, collaborative research between ICRISAT and CRIDA is analyzing the effects of technologies on the roles and responsibilities of women and men. These data will help quantify the significance of gender as a socioeconomic factor in ICRISAT's research in India.

At another level, in December 1993 ICRISAT made presentations at an Indian seminar on *Women in Agriculture: Developmental Issues*, at the National Academy of Agricultural Research Management, Hyderabad. In addition to the seminar participants over 500 farm women viewed the ICRISAT displays, which covered socioeconomic issues and appropriate technologies for women in agriculture.

Explaining ICRISAT's work to women farmers.

ICRISAT has taken a leadership role in the CGIAR with its gender programs, that include an employment policy which actively considers the dual-career family. Women will continue to play a vital role in agricultural development in the SAT as farmers, field workers, homemakers, and increasingly, as research technicians and scientists. ICRISAT recognizes the importance of these agricultural decisionmakers and actively seeks to involve them in its work. Initiatives specifically targeting women's needs will ensure them a more active role in agricultural development.

A visiting scientist from Vietnam working on groundnut rhizobia at IAC.

Integrated Pest Management for Legumes

Farmers commonly apply chemicals to their crops in an attempt to reduce damage from insect pests and diseases. The chemicals do not always work as intended, and in some cases, actually do more harm than good.

When used appropriately, pesticides can provide fast and economical control. Unfortunately, many farmers are frequently unaware of the potentially negative consequences of excessive pesticide use—a resurgence of the targeted pest due to a reduction in natural enemies, emergence of new pests, resistance to chemical controls, and human health and environmental hazards. The concept of integrated pest management (IPM) evolved primarily because overuse of chemicals led to many pests getting out of control.

IPM provides farmers with alternative pest control strategies which do not depend solely on chemicals. It can be defined as farmers managing pests of their crops through activities that maintain the density of potential pest populations below levels at which they become economically damaging, but without endangering the productivity and profitability of the farming system as a whole, the health of the farm family and its livestock, and the quality of adjacent and downstream environments. A successful IPM program is based on a thorough and fundamental knowledge of farming system ecology. Four primary control strategies characterize IPM.

- Host-plant resistance
- Enhanced natural control
- Manipulation of the farming system to minimize pest infestation or damage
- Controlled use of synthetic chemicals or natural control substances

IPM is a dynamic activity that happens in farmers' fields, usually as a consequence of deliberate decisions made by the farmer. It encompasses the results of many years of component research, followed by vigorous technology transfer efforts. There is no standard package of IPM recommendations—one approach does not fit all needs. A set of components must be evaluated under realistic conditions and molded to suit a specific farming system and the available resources.

Cattle egrets can reduce populations of **Helicoverpa armigera.**

ICRISAT scientists have intensively studied the components of an IPM strategy, and can now cautiously approach farmers with the fruits of their years of research on their mandate legume crops—chickpea, pigeonpea, and groundnut.

IPM for Chickpea and Pigeonpea. The potential to successfully manage insect pests varies among the different pulse crops. In South Asia, for example, chickpea is attacked only by *Helicoverpa armigera*, but several effective management tools exist, together with a large database of ecological information. In contrast, pigeonpea is attacked by many insect pests. Unfortunately the reservoir of ecological knowledge, although substantial, does not cover the immensity of the problem.

Chickpea harvest in Nepal.

Chickpea is traditionally grown as a winter-spring crop in the northern part of the Indian subcontinent, at a time when *Helicoverpa* is not very active. Crops that mature by late February or early March avoid damage from this insect, hence the popularity of short-duration varieties in the region.

In the southern part of the Indian subcontinent, the insect remains active throughout the year and is considerably more damaging. In a series of experiments under simulated farm conditions at IAC, scientists demonstrated that if an insecticide is applied during the reproductive stage of the crop when there are more than two larvae per plant, then yields can increase from 0.7 to 2.4 t/ha. This strategy involved two to three applications of insecticide per season. Further research is aimed at finding ways to maintain insect pest levels below the threshold density without using insecticides.

This research includes several strategies that will all need to be tested to find the ones most pertinent to a given situation.

- Growing varieties with resistance to *Helicoverpa* and fusarium wilt
- Growing mixtures of insect-resistant and high-yielding (susceptible) varieties
- Intercropping with plant species that attract larval parasites
- Applying biological insecticides

When insect-resistant and high-yielding (but susceptible) varieties are grown together under experimental conditions, an unknown mechanism apparently provides protection to the susceptible plants. Thus when the mixture is subject to a low level of insect attack the yield will be lower than if only the high-yielding variety were grown, but when insect pressure is high, the mixture will outyield a sole planting of the susceptible, high-yielding variety.

Helicoverpa is also the major insect pest of pigeonpea in the core growing area of southern India, but the podfly (*Melanagromyza obtusa*) is the main pest in northern India, Vietnam, and during part of the season in Sri Lanka. A third insect is the major pest in areas of high humidity. Pigeonpea entomologists have concentrated on *Helicoverpa* because it is the most damaging insect wherever the crop is important.

Low levels of genetic resistance to *Helicoverpa* have been detected in several genotypes which consistently suffer less pod damage than control cultivars when not sprayed, but without sacrificing yield. The mechanism for this resistance is not clear, but researchers are working closely with NARS, NGOs, and farmers as a continuing part of this collaborative on-farm pest management research.

Genetic engineering is a potential mechanism for improving host-plant resistance either by inserting novel genes or through wide hybridization. Recent studies have also shown that the effectiveness of key natural enemies of *Helicoverpa* is influenced by pigeonpea genotype, a factor which will weigh heavily in future breeding efforts.

Another approach to pest management which can be combined with host-plant resistance is the application of natural insecticides. Synthetic insecticides, however, will remain a valuable tool in managing pests of chickpea and pigeonpea, but the widespread misuse of these chemicals has overshadowed their potential benefits. *Helicoverpa* has developed resistance to most classes of insecticide, which effectively eliminates them from management strategies in the long term.

An increasingly affluent urban population is pushing up the demand for the pulses, that form a valuable protein component of their diet. Successful pest management will be the cornerstone of more efficient production systems. In turn, these systems will depend upon farmer-managed IPM.

Groundnut IPM. Many of the world's poorest people depend on groundnut as a cash crop and as an essential part of their diet. In less-developed countries, this legume is grown on about 20 million ha, but few farm families grow more than 0.6 ha in any one season. At an absolute minimum, 30 million farm families are at least partly dependent on this crop for their livelihood, often it provides their only source of cash income.

Resource-poor families work hard to grow the groundnuts on which they depend.

Groundnut yields in the SAT rarely exceed 0.7 t/ha, yet scientists know that even without irrigation this yield can be doubled or tripled. Even though the groundnut plant is naturally resistant to most defoliating insects and pathogens, some pests are out of control. Farmers who have enough money to buy pesticides believe they will insure their crop against insect pest attacks by spraying regularly, irrespective of the relationship of damage to insect population densities in the field. Sadly, the productivity and profitability of their farms have declined over the years.

During the 1992/93 season, pest management specialists from ICRISAT Asia Center and Bapatla College, Andhra Pradesh Agricultural University (APAU) began working with a group of groundnut farmers on the east coast of India. These farmers had been applying insecticides to their groundnuts five or six times during a single 90-day crop cycle. Despite these frequent applications of chemicals, their crops suffered severe attacks from defoliating insects.

Perches encourage birds to stay in the groundnut fields when they prey on pests.

The researchers persuaded the farmers not to apply insecticides or fungicides, unless the need was forecast. Populations of beneficial insects grew, birds and spiders returned to the fields, and insect pests soon became food for a host of beneficial predators. Some insect pests became unwilling hosts of parasites, while insect pathogens spread by the bird droppings killed still more.

One leading farmer stuck small tree branches into his fields to provide perches for birds. This idea was instantly followed by his neighbors. This simple but elegant technique increased levels of pest predation—virtually every perch was occupied. The groundnut yield of the unsprayed crop was at least equal to that of neighboring sprayed crops, but the profit was substantially greater because no money was spent on chemicals.

The news of this success quickly spread, and even in the first season farmers in neighboring villages decided not to apply insecticides to 400 ha of groundnut. Their yields were equal to or better than what they had anticipated. They estimated the increase in profitability to be worth 1 million rupees because they had previously spent about 2500 rupees (US$ 83) per hectare on insecticides.

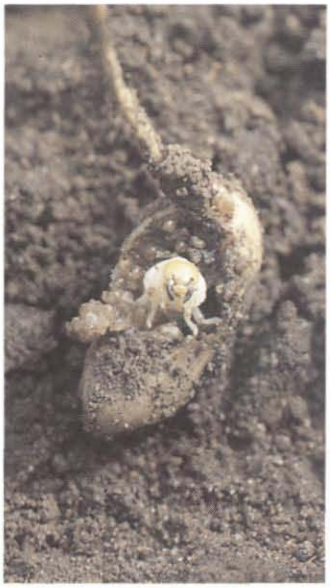
Technical staff acted as pest scouts. They advised farmers daily, warning them if pest outbreaks were forecast. They visited each farmer three or four times a week, operated a pest-forecasting system, and advised farmers to sow specially adapted groundnut varieties by a certain date to avoid the risk of late-season pest invasions. It should be noted, however, that synthetic pesticides are often part of an IPM scheme, but the emphasis is always on applications only when needed, not as part of a routine 'more is better' regimen. In fact, no farmer following the APAU/ICRISAT system needed to apply insecticides.

Rich harvest from unsprayed fields—profits are higher if money is not spent on pesticides.

Over 10 years of research on IPM has vastly increased the understanding of the crop-insect system in groundnut. ICRISAT scientists and their collaborators are now studying how various pest management procedures can be integrated in farmers' fields. The next step to spreading groundnut IPM technology is to train 'pest scouts' and provide them with the skills necessary to advise farmers. The formation of this scout cadre will increase rural employment—especially of women, who are well-suited to this work.

ICRISAT scientists are working on IPM for other crops in other production systems. Basic technologies are available, but no matter what the nature of the crop or production system, the crucial need is to link the farmers' best interests with the various management options through a thorough knowledge of the agroecosystem.

Grappling with Groundnut Grubs



White grubs demolish groundnut pods.

Groundnut is a strategic crop for food security and cash earnings in parts of Asia and Africa. In many countries yields are severely reduced by damage from white grubs, the larval stage of cockchafer beetles, known to many people as May beetles or June bugs. White grubs eat plant roots, and in groundnut, they may also eat the pods. In some areas, such as the Gangetic Plain in northern India, damage has been so severe that farmers no longer grow groundnut.

During an extensive survey of groundnut fields in Malawi, Zimbabwe, Tanzania, and Zambia in 1986/87, an ICRISAT entomologist identified more than three dozen known species of white grubs, and found an equal number that were new to science. White grub population densities were high enough to reduce groundnut yields by at least 50%. It is now known that more than 100 species of white grubs are potential groundnut pests.

Because of the increasing importance of groundnut across the world, ICRISAT scientists are collaborating with Indian and Australian agricultural research organizations to study white grubs and fill in certain knowledge gaps. ICRISAT has a comparative advantage for a portion of this research because of its excellent research facilities at IAC, but relies on its collaborators for field studies with farmers.

White grubs can kill groundnut plants and seriously reduce production.

Despite the importance of groundnut in many countries of the SAT, ICRISAT scientists first had to establish effective research techniques for studying white grub damage. Using these techniques, they investigated the relationship between larval density and groundnut yield, and the response of white grubs to roots of wild species of groundnut. They adopted this latter topic after discovering that another species of soilborne insect does not survive when feeding on the roots of some wild groundnut species.

Experiments in 1993 established that without access to living plant roots, grubs could not survive for more than a month solely on the organic matter present in the soil. Under experimental conditions, larvae reduced pod yield by 17% at densities of 10/m^2 or 25 for every 100 plants, and by 50% at twice that density. Definitive results about the resistance of wild groundnut species are not yet available, but the experimental results to date warrant further studies.

White grub damage is sometimes a sign of increasing prosperity. In some areas of northern India, farmers can afford to buy tractors and are thus able to plow at night when it is cooler. The white grubs that are exposed by cultivation at night are not eaten by birds as are those exposed by daytime cultivation. Night plowing thus eliminates an important natural control mechanism.

ICRISAT has developed a new technique for studying white grubs and applied it to accumulate essential data about their growth rates. This information is needed so that scientists can continue their search for resistance to white grubs in the wild species of groundnut.

If resistance is confirmed, then advanced molecular biology techniques will be adapted to transfer the resistance factors to high-yielding cultivars. The intention is to improve the profitability and sustainability of farms in northern India and Africa by providing farmers with groundnut varieties that can produce good crops even though white grubs inhabit the soil they till.

Studying soil populations of white grubs at IAC.

Insect Pests of Sorghum and Millet

Sorghum and millets are the most dependable crops in many marginal environments, and are usually grown by smallholders. These cereals are important to food security in the SAT because they are particularly well adapted to stress-prone environments.

In many areas, insect pests seriously reduce sorghum grain yields. Cultural control methods are only moderately effective, and using insecticides is problematic—they are expensive for farmers of limited means, may not be available even if farmers can afford them, are potentially dangerous to use, and may be ineffective because insect larvae remain protected inside the plant.

Breeding for host-plant resistance is an effective method of controlling insect pests—farmers who sow the resistant seeds do not need training in pest control

Stem borer larvae can totally destroy millet stems.

techniques, and no cash investment is required. Host-plant resistance is an essential element of IPM, which takes full advantage of natural enemies, agronomic practices, and to a limited extent, chemical control. Traps baited with pheromones —chemical attractants emitted by female moths—are another technology used to help control insect pests.

ICRISAT scientists and their collaborators are working on several fronts to develop IPM strategies to control insect pests of sorghum and millet.

Pearl Millet Stem Borer. This pest is estimated to cause annual yield losses of US$ 91 million in sub-Saharan Africa. ICRISAT researchers at ISC are collaborating with the UK Natural Resources Institute (NRI) to optimize pheromone technology to control the borer (*Coniesta ignefusalis*).

Using sophisticated laboratory equipment, NRI scientists extracted, identified, and synthesized five pheromone compounds which were confirmed to comprise the female sex pheromone of the stem borer. However, through field testing in farmers' fields at Sadoré near ISC, scientists demonstrated that only three of the compounds, if combined in an optimum ratio, are attractive to males. The role of the other two compounds has yet to be determined.

A locally made pheromone trap in on-farm trials in Niger.

Scientists developed a water-based pheromone-baited trap that was tested in farmers' fields. The trap, which can be manufactured locally, has potential for use as part of three different strategies.

- Monitoring moth populations. By counting the number of moths in traps placed in their fields, farmers can monitor population levels and develop an early warning system to determine if the moths reach a level that threatens to cause significant damage to the crop.
- Mass trapping. Using traps to capture large numbers of moths, thereby reducing pest populations, is more efficient for

non-migratory insects. Since it is likely that the millet stem borer is not a migratory insect, the potential for using pheromone traps for mass trapping is high.

- Disrupting mating behavior. This technique uses the female pheromone to chemically disrupt communication between males and females. Using rubber resin dispensers placed at regular intervals, males were successfully confused in a trial in farmers' millet fields. Large numbers of males were caught in pheromone-baited traps in the center of non-treated plots, but almost no catches were made in pheromone-treated plots.

Small pieces of impregnated rubber placed at intervals in the field can emit enough pheromone to disrupt insect mating behavior.

ICRISAT scientists and their collaborators from NRI and NARS in western and central Africa will continue both strategic and adaptive research using pheromone traps to reduce the incidence of the pearl millet stem borer. This research not only has potential benefits for all sub-Saharan countries affected by this pest, but also for other locations where the design of the trap can be adapted to monitor other insects using different moth pheromones. The successful transfer of this technology will help subsistence farmers reduce insect damage and increase millet yields.

Sorghum Midge. This destructive insect pest causes annual losses of US$ 300 million in India, Ethiopia, Tanzania, Yemen, several western African countries, and Australia. In the very worst years, an infestation by sorghum midge (*Contarinia sorghicola*) can cause total crop failure. Chemical control is inefficient and involves costly inputs from farmers. ICRISAT has identified sources of genetic resistance, transferred them into agronomically improved sorghum cultivars, and tested their adoption by farmers.

Extensive studies by ICRISAT scientists have identified the actual midge-resistance mechanisms. Flower characteristics appear to provide the major element of resistance to midge attack. In midge-resistant genotypes, a short and tight glume covering over the ovule keeps the insect from attacking the grain. In other resistant genotypes, adult insects are not attracted for several reasons.

- Chemicals in the plant, if eaten, kill the larva or pupa or prolong their development by 5 or 10 days so plants escape damage
- Shapes and sizes of flower parts are associated with midge resistance, a characteristic which can be used as a marker to select for resistance

- The grain of some midge-resistant lines develops faster than that of susceptible lines immediately after pollination and thus avoids midge damage
- Some of the most midge-resistant lines have a high tannin content and therefore may be unpalatable to insects

The ICRISAT-developed midge-resistant variety ICSV 745 yields 50 to 100% more grain than commercial cultivars in areas where midge is endemic. The use of this dual-purpose variety for grain and fodder production drastically reduces both the build-up of midge populations and farmers' investments in insecticides. A significant contribution to environmental sustainability, it has been tested extensively in India on farmers' fields by ICRISAT scientists in collaboration with the University of Agricultural Sciences in Karnataka, and ISPA in Andhra Pradesh.

ICSV 745 has been released for cultivation in Karnataka as DSV 3, and has also performed well in on-farm trials in Andhra Pradesh and Tamil Nadu, and in Sudan.

A healthy crop of ICSV 745 growing in a midge-endemic region of Karnataka where midge-susceptible sorghums suffer heavy damage.

Another midge-resistant variety ICSV 88032 is being tested as SPV 1010 in India by the All India Coordinated Sorghum Improvement Project. ICSV 746 and ICSV 735 are being tested in Myanmar, and ICSV 735 will be tested on-farm in Sudan.

Within the next two or three years midge resistance will also be transferred into hybrid sorghums. This will offer farmers the change to minimize the risks of loosing their crops, and will help to increase sorghum productivity in endemic areas.

Sorghum Head Bugs. In a collaborative project between ICRISAT and the Cereals Technology Laboratory of the Centre de cooperation internationale en recherche agronomique pour le développement (CIRAD) in France, scientists identified a major factor associated with resistance to head bugs—quicker hardening of the endosperm, which shortens the period during which head bugs can feed and lay their eggs in maturing sorghum grains.

Host-plant resistance to the sorghum head bug (*Eurystylus immaculatus*)—which causes an estimated worldwide yield loss of US$ 200 million each year—is the best mechanism by which to increase and stabilize grain yield. Over 1000 genotypes have been evaluated for resistance under field conditions. Of the improved varieties, Malisor 84-7, bred by ICRISAT scientists working in Mali, is the most promising source of resistance. Multilocational trials from 1989 to 1993 in Mali, Burkina Faso, and Nigeria confirmed the high level and stability of head bug resistance in this variety.

Evaluation of breeding lines derived from crosses between Malisor 84-7 and high-yielding cultivars under both natural and artificial head bug infestation confirmed resistance. Breeding and collaborative trials with NARS will continue as scientists exploit this genetic resistance to an economically important insect pest.

Adult sorghum head bug feeding on developing sorghum grains.

Improving Sorghum and Pearl Millet

LASIP's 16-Year Impact. The ICRISAT Latin American Sorghum Improvement Program (LASIP) has had a profound impact on the region during the last 16 years.

Thirty sorghum cultivars based on materials identified or bred by LASIP have been released in 10 Latin American countries, and are now grown commercially on 97,000 ha. The program has also benefitted smallholders in the region, who grow much of their sorghum in cool, high-elevation environments.

ICRISAT scientists also introduced superior lowland tropical germplasm for intermediate and low elevations. They bred for tolerance to foliar diseases, reduced plant height to lower competition with maize in intercropping systems and improve resistance to lodging, and improved the forage quality of local sorghums.

In Guatemala, El Salvador, Honduras, and Nicaragua, sorghum cultivars released via LASIP are grown on 27% of the total sorghum area. Based on preliminary data, the 1993 value of the yield gain as a result of growing these cultivars was US$ 18 million.

LASIP was an important influence in the region because of its strong collaboration with national programs, its supply of superior genetic material backed by appropriate technologies for evaluation and use, and its sustained training program.

In Honduras sorghum grows in cool high-elevation environments. ICRISAT has helped breed well-adapted varieties.

LASIP traces its origins to a Rockefeller Foundation cooperative research program with the Mexican Ministry of Agriculture which began in 1943. ICRISAT's sister institute the Centro Internacional de Mejoramiento de Maïz y Trigo (CIMMYT) started a sorghum breeding program in collaboration with the Mexican national program in 1973. In 1977, ICRISAT assumed responsibility for the program and posted a breeder at CIMMYT's headquarters. In 1982 an agronomist was added to the program to take breeder's products to farmers' fields, study their adaptation to local environments and cropping systems, and exchange information on performance and farmer needs.

New sorghums spread fast through the CLAIS network that links growers in 19 countries.

Also in 1982, LASIP and national sorghum program coordinators from nine Mesoamerican and Caribbean countries formed the Comisíon Latinoamericano de Investigadores en Sorgo (CLAIS), the regional sorghum research network. In 1991, 10 South American countries joined their neighbors in CLAIS.

LASIP's close collaboration with national programs included continual evaluation of germplasm accessions. It provided material to NARS, and organized regional trials for yield, agronomic traits, and food quality through the CLAIS network, and informal bilateral agreements with individual countries. LASIP helped NARS with technology transfer, collaborated in on-farm trials, and offered training to over 130 national researchers, including 71 who studied at IAC.

LASIP concluded at the end of 1993. Provided funding can be found, ICRISAT proposes to continue its activities in Latin America as a component of the ecoregional initiative on acid soils in savanna farming systems led by CIAT, our sister institute in Colombia. The savanna lands are a strategic regional resource, and ICRISAT expertise in sorghum genetics, breeding, and disease management can be a key contribution to the development of sustainable farming systems in the region. The proposed program will also involve INTSORMIL, and hopefully be funded by the Inter-American Development Bank. The network component will involve assembly and dissemination of appropriate technologies to participating NARS through CLAIS.

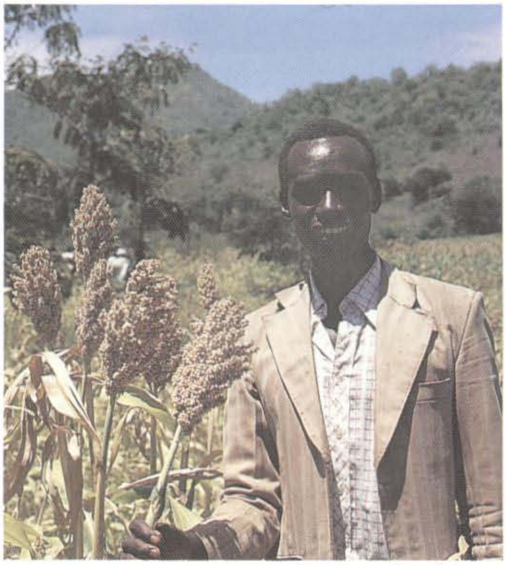
Highland Sorghum for Eastern Africa. Sorghum is an important staple cereal crop for smallholders on 800,000 ha in the cool tropical highlands of eastern Africa, as well as in the higher elevations of Lesotho and Yemen. The highlands where sorghum is cultivated range from 1500 to 2000 m above sea level (asl), and have mean temperatures below 18°C during the growing season. Late-maturing landraces predominate, but are susceptible to leaf diseases and have poor grain quality. To flower and set seed effectively in these cool environments, the crop needs to tolerate low temperatures. Resistance to leaf diseases is also important.

ICRISAT, the Kenya Agricultural Research Institute (KARI), the University of Nairobi, and Egerton University are collaborating to select and breed sorghum for the highlands.

Trials are sown at 1800 to 2100 m asl in Kenyan locations, and multilocational testing extends to the highlands of Burundi, Ethiopia, Rwanda, and Uganda. Materials bred by this research program will enter preliminary yield trials during 1994.

Local sorghum growing at 2200 m asl in southwestern Uganda.

Multilocational and on-farm testing in collaboration with NARS will begin in 1996, and improved cold-tolerant cultivars are expected to reach farmers in 1998. This research was funded by the United States Agency for International Development (USAID) through the Oganization of African Unity/Semi-Arid Food Grain Research and Development (OAU/SAFGRAD). Unfortunately, the cessation of this funding has inhibited further progress.


Kenyan participant in on-farm trials of sorghum KAT 369.

New Sorghum for Kenya. A white-seeded sorghum is a promising new variety from KARI. The variety, KAT 369, is especially attractive to Kenyan policymakers—the country currently imports about 50% of its annual wheat requirements, but flour from this sorghum blends well with wheat flour for baking, thus saving foreign exchange.

KAT 369 was selected in 1983 by KARI breeders from a sorghum nursery sent to them and other NARS breeders from IAC. It has undergone extensive testing by KARI, including on-farm trials in sorghum-growing areas of Kenya.

ICRISAT increased seed at the Kiboko Research Station from 1991 to 1993, and provided it to extension agents and NGOs for use by farmers in the Kiboko area. In on-farm trials in this area conducted by the Kenyan extension service during the 1992/93 short rains, yields averaged 4.1 t/ha, compared to an average of 3.2 t/ha for maize.

Improved Pearl Millet Reaches West African Farmers. Pearl millet varieties developed by ICRISAT and its NARS collaborators in western Africa are beginning to reach farmers' fields.

Over the last two years, ICRISAT has provided nearly 400 kg of seed of these improved varieties for on-station and on-farm trials conducted by the participating countries of the Réseau ouest et centre africain de recherche sur le mil (ROCAFREMI). Experience has shown that dissemination of improved varieties can be quantified wherever seed production and distribution projects are operating. During 1993, ICRISAT and its NARS partners contributed 12 of the 19 varieties to regional trials coordinated by ROCAFREMI for the Sahelian and Sudanian Zones.

Pearl millet variety ICMV-IS 88102 has shown stable and superior performance in on-farm and on-station trials in Burkina Faso and Mali, and was released in Burkina Faso in 1993. Early in the same year, the Institut d'études et de recherches agricoles

(INERA) of Burkina Faso multiplied 2.5 t of three released varieties and one pre-release variety to meet increased seed demand.

In 1992, the Malian Institut d'économie rurale (IER) multiplied 2 t of seed of ICMV-IS 88102 for on-farm trials at 30 locations in 1993. This variety was named *Benkadi Nio* ('friendship millet') by IER to signify the beneficial collaboration between IER and ICRISAT over the last several years.

In Mauritania, four varieties are being multiplied for distribution to farmers, and ICRISAT will multiply a further 100 kg of breeders seed of these varieties to meet future needs. In Senegal, Cameron, and Ghana other varieties from the successful collaboration among ICRISAT and its West African NARS partners are in various stages of on-station and on-farm testing, seed multiplication, and release.

Major Donor Confirms Support

Crop improvement is a lengthy process which can take 15 to 20 years to achieve significant results in farmers' fields. Nonetheless, the joint efforts of national and ICRISAT scientists working on sorghum and pearl millet in southern Africa have already borne fruit in several countries. And the major donor, the United States Agency for International Development (USAID), has displayed its confidence in the impacts of the decade-long program by renewing financial support for an additional five years.

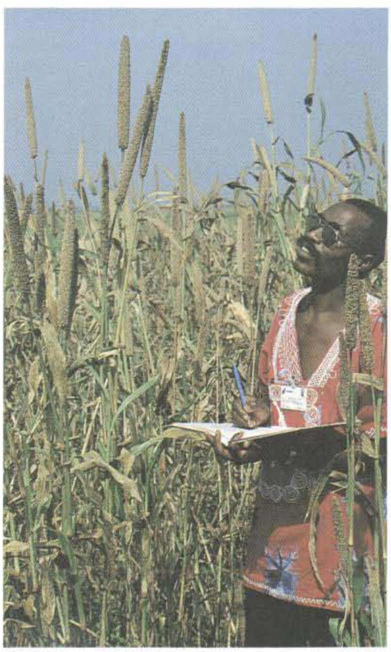
Sorghum and pearl millet are strategically important crops in the semi-arid areas of southern Africa. These drought-prone areas are home to more than 20 million people who are among the poorest in the region, and whose food supply is the most insecure. Most small-scale farmers grow sorghum or pearl millet because their relative drought tolerance provides food security in a tough environment. These crops cover about 2 million ha, roughly one-quarter of the region's total cereal-growing area, and provide about 20% of its total grain production.

Pledging support for continued research.

Trial plots at Matopos, Zimbabwe—the home of the SADC/ICRISAT Sorghum and Millet Improvement Program.

The harsh environment and the historical lack of investment in technology both contribute to the low productivity of these crops in the region.

Ten years ago, the governments of the southern African region asked ICRISAT to implement a regional program funded by USAID. Today, the 10 countries of the Southern African Development Community (SADC) collaborate closely with the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP). Together they work to strengthen research programs and scientific talent in the region. The generous contributions of USAID were augmented by the Canadian International Development Agency (CIDA) in 1986, and by the German funding agency Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung/Deutsche Gesellschaft für Technische Zusammenarbeit (BMZ/GTZ) in 1988. In a special initiative supported by both USAID and CIDA during the 1992 dry season, SMIP managed seed production of improved sorghum and pearl millet varieties under irrigation to help farmers in the area recover from the devastating drought of 1991/92.



Playing a key role in collaborative work, Namibia's pearl millet breeder working on his crop during a visit to IAC.

Thus far, 15 improved sorghum varieties and 5 pearl millet varieties that were bred with ICRISAT or SMIP involvement have been released by SADC national programs. In Zimbabwe 37% of the total sorghum area was sown with variety SV 2 during the 1992/93 growing season, with a total production of 50,000 t. During the same season, the variety Okashana 1 accounted for about 35% of the total pearl millet area in Namibia, yielding over 40,000 t.

An impact study estimated an annual US$ 4.5 added value to Zimbabwean and Namibian farmers from the adoption of just two of the 20 improved varieties which have been released by collaborating SADC national programs. At that rate, the pay-back period of the entire investment in SMIP will be less than nine years, from only a fraction of the technology options which it has generated.

In its Phase III activities, SMIP will concentrate on working with national programs to promote technology transfer to small-scale farmers. This involves strengthening the links among research, extension, farmers, NGOs, seed companies, and markets.

Improving the productivity of national sorghum and pearl millet staff remains an important goal of the project. By 1994/95, nearly 100 scientists will have received postgraduate degrees which have enhanced their skills in the necessary disciplines. Most attended universities in the USA or Canada, but scientists from Angola and Mozambique studied at Brazilian universities in order to avoid language barriers. Many of these scientists—no matter where they studied—received hands-on experience by conducting their thesis research in collaboration with SMIP researchers. In addition, over 240 scientists and technicians from the southern African region have received training at IAC.

Collaboration is important in SMIP's approach to strengthen research through annual workplans developed with national scientists. This approach involves an equal partnership in research, data analysis, interpretation, and reporting. SMIP will also continue its collaborative efforts to breed improved cultivars, collect and exchange germplasm, develop technology to manage insect pests and diseases, and evaluate grain quality.

Families need food security; collaborative programs can help them to achieve it.

Along with seeking to improve production, SMIP will work to enhance the capabilities of national programs to conduct sorghum and pearl millet research. The development and adaptation of improved technology, new cultivars, and better production methods for these crops is a crucial component of food security in drought-prone areas of southern Africa.

Stalking the Elusive Pearl Millet Genes

ICRISAT pearl millet breeders now have a new tool in their research kit: a map of the pearl millet genome.

Growing pearl millet at the desert margins.

Developed using advanced biotechnological techniques, this 'linkage' map will allow scientists to reduce the time necessary to breed new cultivars. With the molecular markers that this tool provides, plant breeders can determine which plants in a new generation contain specific genes of interest—without growing the plants to maturity and evaluating their performance. Breeders will now be able to accomplish in one generation what formerly required several years of expensive, time-consuming multilocational evaluation.

Pearl millet is the staple cereal for millions of the world's poorest people. They live in the hottest, driest areas of the world, where no alternative crop can provide the food and fodder they need to survive in these inhospitable regions—the arid margins of the SAT.

Downy mildew is the single most important biological constraint to pearl millet production. This disease is caused by a highly variable fungus, *Sclerospora graminicola*, which is capable of multiplying to epidemic proportions when presented with large areas sown to uniformly susceptible pearl millet in an environment congenial to disease development.

For 21 years ICRISAT scientists have collaborated with their NARS partners to breed new genotypes of pearl millet resistant to stresses that reduce yields, or in severe cases, wipe out entire crops. This is a challenging goal. It is important to recognize that scientists are attempting to improve upon landrace varieties that have been selected by farmers over hundreds of years. Not surprisingly, conventional plant breeding is time-consuming and expensive. The stable performance of a new variety in an environment where the stress occurs must be confirmed by large numbers of trials grown at many locations over many years before its release can be justified.

A conventional breeding program typically takes 10 to 15 plant generations to move from the initial cross to finally identifying and perfecting a product suitable for farmers' fields. During this long process, over 99.9% of what is developed is discarded. And only about one of three products that make it through to release by national programs is ever widely adopted by farmers, even after extensive evaluation and on-farm testing.

Collaborators in the UK. ICRISAT is working with two collaborators in the UK funded by the Overseas Development Administration (ODA): the Cambridge Laboratory, Norwich, and the Centre for Arid Zone Studies, University of Wales, at Bangor. ICRISAT scientists (funded by the United Nations Development Programme-UNDP) have helped these collaborators develop the gene map of pearl millet, and use the map to locate downy mildew resistance genes. The resistance to this major fungal disease has long been known to be inherited, but scientists did not have a good understanding of the genetics of resistance, the variability of the downy mildew fungus, or how resistance works. With the aid of the new map, plant breeders now know where in the pearl millet genome the resistance genes effective against specific isolates of downy mildew are located, and can use this information to incorporate this resistance systematically and deliberately into improved varieties.

Sclerospora graminicola *causes downy mildew disease of pearl millet.*

Scientists at Bangor have screened two sets of pearl millet mapping progenies against downy mildew isolates from four countries—India, Niger, Nigeria, and Senegal. In the two resistance sources evaluated thus far, there are genes contributing to downy mildew resistance on five of the seven pearl millet chromosome pairs. Each of these genes is effective against only one or two of the downy mildew isolates. For a plant to have resistance effective against all four isolates, it must have a pyramid of three or more resistance genes.

ICRISAT breeders have started a backcross program to transfer appropriate parts of the mapped downy mildew resistance into three female parents of pearl millet hybrids commonly used in Indian breeding programs. In addition, they are using backcrossing to incorporate downy mildew resistance from these sources into the open-pollinated variety CIVT, which is moderately susceptible to downy mildew, but has been one of the few improved pearl millet varieties that consistently outyields farmers' landraces in West Africa.

Collaborators in India. ICRISAT scientists and their collaborators in the UK and in national programs are now mapping genes for resistance from other sources of stable downy mildew resistance. The objective is to identify molecular markers for resistance genes located at other positions in the pearl millet genome. The Indian Agricultural Research Institute, New Delhi, and the Tamil Nadu Agricultural University, Coimbatore, helped choose the parents of the next crosses to be mapped, and will assist in field evaluation of the mapping progenies. Researchers at the University of Hyderabad will collaborate with ICRISAT and UK scientists to map two of the pearl millet chromosomes, about which information is currently very scarce. Researchers have begun to evaluate the performance of the progenies from a second set of mapping populations targeting tolerance of seedlings to heat, another key adaptive trait for reliable pearl millet production.

Advantages of Gene Mapping. Gene mapping is an important new tool in plant breeding which has the potential to reduce the time required to achieve a given genetic advance. It must be tied to an applied breeding program, however, if investments in the technology are to benefit farmers and consumers. Higher productivity from successful new plant cultivars lowers the unit cost of production; both farmers and consumers then benefit from the investment in research.

The pearl millet gene map is short. It is ironic that because the genome is small, this orphan crop, grown and eaten by millions of the world's poorest people, is now of interest for basic genetic studies at laboratories all over the world. It is much less expensive to study than rice, maize, or wheat. Within three years, ICRISAT scientists and their collaborators will identify markers for blocks of resistance genes from additional sources of stable resistance to downy mildew, and use molecular marker assisted backcrossing to transfer relevant downy mildew resistance genes into agronomically elite, economically important female parents of hybrids that lack adequate resistance to this disease.

This partnership on molecular gene mapping among UK, NARS, and ICRISAT collaborators offers several advantages over a conventional breeding program.

- Breeders can screen in the laboratory for resistance against different strains of a pathogen without waiting for results from multilocational trials or moving potentially dangerous disease organisms around the globe. Expenses for laboratory screening are much lower than those for field screening.
- Because there is no need to introduce the actual pathogen for screening, cultivars for Africa can be screened at IAC that formerly would have been screened either in Africa or in a 'neutral' safe country where no pearl millet is grown. For example, once tags for downy mildew resistance genes effective in Nigeria (or any other country) have been identified, it becomes possible to select with confidence for this resistance anywhere in the world.
- Breeding objectives that were formerly technically possible but wildly impractical now will be reasonable; for example, backcross transfer of fertility restoration genes. Tags for these genes would allow scientists to 'correct a flaw' in a hybrid that was excellent in all respects except its ability to produce enough pollen to ensure good seed set when grown in an isolated field.
- Farmers will have an opportunity to choose from a wider range of cultivars in a shorter period of time. There will be a shorter lag time between the investment in research and the pay-off from improved varieties in farmers' fields. Thus the rate of return on investment in pearl millet improvement will be even higher than before.

Discussing farmers' preferences for pearl millet types in Rajasthan.

Searching the Cytoplasm

Growing hybrids is an important management strategy for many different crops. ICRISAT scientists now have a new tool to save time and money in their hybrid breeding program—DNA analysis to characterize the cytoplasm (the portion of a single cell that surrounds the nucleus). This technique saves time and money in breeding two crops grown and eaten by millions of people in the SAT—pearl millet and pigeonpea.

And in another application of advanced technology in breeding pigeonpea, scientists have developed a technique to cross cultivated varieties with previously incompatible wild relatives that have desirable characteristics.

Male-sterile pearl millet (left) has florets with stigmas and nonfunctional anthers, unlike the florets (right) that are ready to release their pollen.

Hybrids. The progeny of a cross between two genetically dissimilar parents is a hybrid. One of the advantages of growing hybrids is that they can express vigor—higher yields, more uniformity, and greater vegetative growth than open-pollinated varieties—which means more food and more income for the farmer.

In the absence of an effective way to protect plant varieties, the private sector prefers to invest in crop improvement research in species where hybrid seeds are used. The hybrid seed industry offers commercial opportunities because research investments can be protected by keeping the parentage of hybrids confidential. Developing commercially viable methods for producing hybrid seed encourages private investment in crop improvement, and hence a broader range of genotypes from which farmers can choose.

In order to produce commercial quantities of hybrid seed, one of the parents must be a male-sterile—a plant that does not shed viable pollen while remaining female-fertile. Farmers who grow seed for field crops prefer to use cytoplasmic male-sterility systems rather than genetic male-sterility systems because the labor requirements for hybrid seed production are lower. Cytoplasmic male-steriles can be maintained so that all plants in the next male-sterile generation—used to produce hybrids—are sterile. Using genetic male-sterility, however, only half of the generation grown to maintain the male-sterility is sterile, and thus the flowers of all the plants in a field must be examined and the male-fertile plants removed—a highly labor-intensive and expensive process.

Male-sterile lines can be used as female parents of hybrids by growing them near another parent which is male-fertile and thus a source of pollen. All seed produced on the female parent results from fertilization by this pollen if the two parents are sown in isolation from other pollen sources. This economical technique produces 100% pure hybrid seed.

Of course, widespread use of this neat and economical system is possible only if the male sterility is stable across seasons and locations. Also, the cytoplasm must not adversely affect grain yield, disease and insect resistance, or any other traits of economic importance.

Plant breeders want to identify new sources of cytoplasmic male-sterility in order to widen the genetic base of hybrids. Genetic diversification reduces the risk of epidemics associated with genetic uniformity.

Pearl Millet. Currently all pearl millet hybrids worldwide are based on a single cytoplasm, a risky situation should a fungus or other pest evolve that is especially well adapted to that cytoplasm. This has happened in the past—in the early 1970s, about 25% of the hybrid maize crop in the USA was destroyed by southern corn leaf blight because the hybrids were all based on a single cytoplasm.

It is strategically important, therefore, to broaden the cytoplasmic base of cultivated pearl millet. At IAC, scientists are now using DNA analysis to characterize pearl millet cytoplasms, a technique that cuts years off the field characterization process that involves careful hybridization and evaluation of progenies. Thirteen cytoplasmic lines were DNA-analyzed, and they formed four major groups, each of which represented a particular DNA hybridization pattern. A fifth group was identified later. Two of these groups are from wild species of pearl millet. The laboratory DNA analysis confirmed the grouping that plant breeders had been using, and scientists are now integrating laboratory data with breeders' field data.

Breeders can now use DNA analysis to confirm or deny the existence of a new male-sterilizing cytoplasm without field trials. This saves an enormous amount of time and effort. If the analysis shows a plant to have a new and unknown cytoplasm, then the breeder grows field trials to help characterize it. In the mid-1980s, breeders at IAC invested years of field studies in a male-sterile line that they suspected had a different cytoplasm, but the results were inconclusive. DNA analysis has now shown that this cytoplasm is different, which agrees with current field studies.

The identification of a new source of cytoplasmic male-sterility is important because it give the breeders an additional backup if a pathogen or other pest evolves to which the cytoplasm is susceptible. Pearl millet breeders internationally now have three quite different backups for cytoplasmic male-sterility, representing an important payoff from a strategic research investment in pearl millet improvement.

Pearl millet hybrid seed production, based on cytoplasmic male-sterility, generates income for small-scale farmers.

Pigeonpea. In the late 1970s, two genetic male-sterile lines were discovered in pigeonpea which made it possible to breed and release the world's first pigeonpea hybrid in India. Commercialization of this hybrid is problematic, however, because seed production with genetic male-sterility is labor-intensive and off-type fertile plants in female parent rows in the seed production fields call into question the purity of the hybrid seed.

There have been modest yield gains in pigeonpea productivity through breeding for resistance to pests or changes in agronomic practices, but more substantial and rapid genetic yield improvement in pigeonpea could be gained through hybrids. Despite the problems with hybrid seed production, the technology is a breakthrough.

In the search for cytoplasmic male-sterility in pigeonpea, breeders attempted conventional backcrossing using a wild species of pigeonpea as the female parent and cultivated varieties as the male, but were unsuccessful because the progeny reverted to fertility. However, by using four different cultivated parents, scientists found that the cytoplasm does induce male sterility that can be maintained by cultivated pigeonpea.

This discovery at IAC in late 1993 of cytoplasmic male-sterility in pigeonpea has the potential to revolutionize the hybrid seed industry for this crop. Breeders will be able to select for desirable traits in breeding lines more quickly and confidently. Using the stable cytoplasm, they will now look for high yields and other favorable characters in cultivated lines. Further, private investment in pigeonpea improvement can be expected to increase substantially once practical and economic hybrid seed production is demonstrated using the cytoplasmic male-sterility system.

Using Wild Relatives. It is essential to have a range of cytoplasmic male-sterility systems to maintain diversity in a crop. Wild relatives of pigeonpea are one source of different cytoplasm—numerous wild relatives are possible sources of different cytoplasm and also have other interesting traits, but until now it has not been possible to cross some of the wild species with cultivated varieties.

During 1993, ICRISAT scientists working at IAC successfully adapted the 'embryo rescue' technique so that they could cross incompatible wild pigeonpea species with cultivated varieties.

One of the previously incompatible species, *Cajanus platycarpus*, that is highly resistant to phytophtora blight can now be crossed with the cultivated species, using the embryo rescue technique, thus making it possible to transfer this highly desirable characteristic. This wild species also flowers profusely, resists the pod borer, sets many pods, and has a high biomass—all desirable traits for a food crop plant. At IAC, the embryo of a cross between C. *platycarpus* and a cultivated variety was successfully rescued and grown. But the second generation did not set mature seed, so there is a need to 'rescue' that generation also.

ICRISAT biotechnologists will continue using the embryo rescue technique to produce succeeding generations until they can successfully produce a plant that does set mature seed.

The goal is to produce interspecific hybrids that can be crossed with the cultivated types without using the embryo rescue technique, thus making available a range of cytoplasms and other desirable traits from wild species for use in breeding cultivated varieties.

Interspecific hybrid plant grown from a rescued embryo.

Pigeonpea in Africa

Pigeonpea is an important crop in the SAT because it tolerates drought, producing a relatively high grain yield on limited residual moisture. Although India dominates the world production of pigeonpea, farmers in Africa annually grow about 167,000 t on over 273,000 ha—just under 6% of world production.

Pigeonpea has a protein content of up to 28%, which makes it an excellent complement to protein-deficient diets that are composed mainly of cereal or root crop carbohydrates. Wide variation in plant types and maturity groups permits pigeonpea to fit into numerous production systems, along with the additional benefits of fixing atmospheric nitrogen and recycling soil nutrients. Pigeonpea leaves are important as livestock fodder, and the stems are commonly used as fuel. Production is growing slowly (about 1.5% annually) in eastern and southern Africa. With support from the African Development Bank (AfDB), ICRISAT is working with NARS partners to adapt the crop to African production systems and develop new markets.

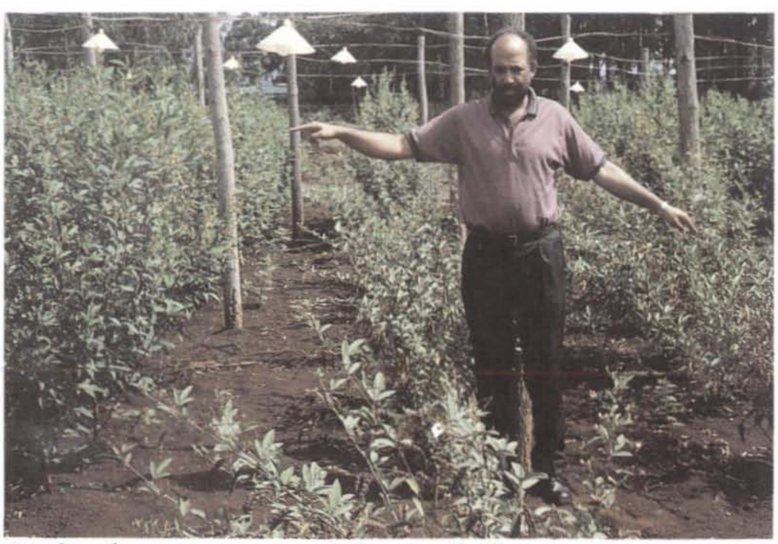
Adaptation to Multiple Environments. Pigeonpea is extremely sensitive to environmental factors, particularly daylength and temperature. Time-to-flowering, plant height, biomass, and grain yield are all affected by these sensitivities, which are a major constraint to the development of management practices, production systems, and new varieties.


An ICRISAT technician examining a Kenyan farmer's pigeonpea crop.

Because plant height is unstable, for example, it is difficult to make general recommendations for sowing rate, spraying, and harvesting. A delay in flowering, and a consequent delay in maturity, may interfere with a well-developed cropping sequence if the time between harvesting pigeonpea and sowing a succeeding crop is shortened. Delay in flowering may also reduce yield in areas where the crop depends on residual moisture but the rainfall duration is short. Accelerated flowering can be just as problematic—if the reproductive growth phase occurs between rains in a bimodal rainfall area, the crop may suffer from drought stress.

In eastern and southern Africa, pigeonpea is grown at altitudes varying from sea level to about 1800 m asl. The medium- and long-duration lines developed at IAC that show high potential in India perform very poorly in Africa. Similarly, extra-short- and short-duration pigeonpeas, while relatively insensitive to daylength, are still sensitive to temperature.

Attempts to introduce pigeonpea that is in local high demand as a dry pulse crop into wheat rotations in the Kenyan highlands have not been successful because pigeonpea is sensitive to low temperatures.


Daylength, temperatures, and altitude all affect pigeonpea genotypes.

ICRISAT scientists, together with collaborators from KARI, grew 121 short- and extra-short-duration and 48 medium- and long-duration pigeonpea lines of diverse origin at four locations in Kenya with altitudes varying from 50 m to 1800 m asl, with the consequent temperature and daylength regimes. The aim of the study was to gather information so that ICRISAT and KARI scientists can understand the influence of temperature and daylength on different pigeonpea genotypes, and then develop breeding strategies and recommendations for specific production systems.

Although data analysis is continuing, preliminary results indicate that medium- and long-duration genotypes must be developed for specific environments.

An excellent type of pigeonpea that can be eaten as fresh green peas.

- Genotypes developed where average temperatures are low will have delayed flowering, or fail to flower at all in areas where temperatures are higher
- Long-duration genotypes developed in areas with high average temperatures will flower early in areas with lower temperatures
- Long daylength appears to delay flowering more in areas with high temperatures, and the best location at which to screen for insensitivity to daylength is probably an area with high temperatures

Short- and extra-short-duration lines also have specific requirements. The trials indicated that these types can be grown in medium- to high-altitude areas, but the delay in time to flowering and maturity in areas with bimodal rainfall may interfere with the cropping sequence. Flowering and maturity were earliest where the average temperature was high, and plant height was reduced at higher elevations. Scientists are analyzing the data to select lines adapted to high altitude and low temperature.

Green Vegetable Pigeonpea. In eastern and southern Africa, pigeonpea is consumed as food cooked from the dry grain or eaten as a fresh green vegetable. When grown as a fresh vegetable, pigeonpea is harvested when pods are full but still green. The green seed, which is boiled before it is eaten, is more nutritious than the dry seed because it not only contains more proteins, sugar, and fat, it is also more digestible.

This Kenyan farmer built a new grain store with profits from her fresh green pigeonpeas.

A small quantity of green pods is exported from Kenya to the UK for consumption as a fresh vegetable, but production is far below its export potential. ICRISAT and its collaborators are identifying green vegetable pigeonpea varieties that could boost production.

This crop is a valuable addition to production systems in eastern and southern Africa. The consumption of pigeonpea as either a fresh green vegetable or dry grain offers marketing flexibility to farmers, as well as an opportunity to expand and diversify their production systems. If exporters fail to receive orders from abroad, growers of green vegetable pigeonpea have the option to let their crop mature and harvest it as grain.

Chickpea Advances

ICRISAT shares the world mandate to improve chickpea with its sister institute, the International Center for Agricultural Research in the Dry Areas (ICARDA). This legume is a vital crop in large areas of the SAT—the seed provides valuable protein in many diets, crop residues are used as animal fodder, and nitrogen fixed in root nodules contributes to crop growth and increased soil fertility. Chickpea is the second most important pulse crop of rainfed agriculture in at least 33 countries. It covers 15% (9.6 million ha) of the world area of pulses, and 13% (5.6 million t) of world pulse production.

Two Traits for the Price of One. Chickpea is often grown in areas where temperatures may drop to 0°C. Without tolerance to low temperatures, plants may be damaged, or production adversely affected, depending on the growth stage of the plant when the temperature drops. Over a decade ago, ICRISAT breeders detected tolerance to low temperatures in a breeding population, and evaluated this trait in subsequent generations. One of the parents of the original material in this trial was collected in Russia and sent to IAC by an Australian collaborator as a possible source for cold tolerance.

But while the breeders were selecting for cold tolerance in trials at Hisar in northern India, they realized that although this genotype grew to maturity in cold regions faster than did conventional cultivars, the yields of the cold-tolerant and conventional cultivars were virtually identical. Thus in addition to tolerating low temperatures, this genotype had a second desirable trait: earliness. By producing a fully mature crop early in the season, chickpea avoids some plant diseases, including ascochyta blight which can build up with the rains, and pod borer populations that increase rapidly after the cold season.

When cold-tolerant genotypes were sown at IAC, they matured earlier or at the same time as the traditional material, yet the yields were comparable to those of common varieties. Scientists are now breeding to widen the adaptation and stability of early-flowering, cold-tolerant chickpea. These genotypes have not yet been entered in Indian national trials, but chickpea breeders as far apart as Pakistan and New Zealand, as well as those in the Indian national program, have all shown interest in the breeding program for cold tolerance. In the West Asia North Africa (WANA) region, chickpea is sown during spring mainly to avoid damage from cold and ascochyta blight. Now, after years of research, winter sowing of chickpea with cold-tolerant and blight-resistant cultivars has been introduced in the WANA region with numerous advantages, including increased yield and water-use efficiency, mechanized harvesting, and high nitrogen fixation and protein harvest per unit area.

Field-screening chickpea for cold tolerance in Syria.

The ICRISAT/ICARDA chickpea project in Syria has developed a field-screening technique to evaluate germplasm and breeding lines for tolerance to cold. Using this technique test material is sown in autumn, two months before normal winter sowing, so that it is in the late vegetative stage before the onset of severe winter temperatures in the later part of December. Material is evaluated for cold tolerance after the susceptible control has been killed by cold. Using this technique, 10,000 germplasm accessions have been evaluated and many sources of resistance have been identified. Among these, ILC 8262 and ILC 8617 can tolerate temperatures as low as $-10°$C for a period of 60 days. The cold-tolerant sources have been used in breeding programs to develop cultivars for winter sowing in WANA.

Overcoming Ascochyta Blight. The development of ascochyta blight resistant, cold-tolerant chickpea cultivars by an ICRISAT/ICARDA project has made winter sowing possible, with a yield advantage of 50 to 100% over the traditional spring sowing. In 1992/93, farmers in the WANA region sowed 93,000 ha of winter chickpea for additional annual income of US$ 11.4 million. Scientists estimate that there is potential for expansion to 2 million ha, with additional annual income of US$ 245 million. Winter sowing will also help sustain the cereal-based (wheat/barley) cropping system by bringing chickpea into the rotation.

Chickpea crops like this one in the WANA region can be devastated by ascochyta blight. Using resistant cultivars bred by the ICRISAT/ICARDA project can prevent disastrous losses.

In the Mediterranean region chickpea is traditionally sown in the spring to grow on residual soil moisture in areas with an annual rainfall of 350 to 500 mm. But by sowing in the winter, chickpea can be grown in areas with as little as 250 mm of annual precipitation because the crop grows during the rainy season when temperatures and evapotranspiration are lower. In dry areas of the WANA region, the normal fallow period can be used to grow chickpea, which provides a sustainable protein-rich alternative to the traditional barley crop grown in other production systems.

Scientists working at ICARDA developed an efficient and cost-effective technique to screen for resistance to ascochyta blight by using diseased debris from the previous season to infect the screening plots. More than three dozen resistant lines were identified after evaluating about 20,000 germplasm accessions. A strong breeding program and extensive international and on-farm testing have led to the release of 50 blight-resistant cultivars by 18 NARS. Similar successes are expected on the Indian subcontinent.

Resistance to Fusarium Wilt. One of the more serious fungal diseases of chickpea is caused by *Fusarium oxysporum*. Seedborne pathogens can be controlled by fungicidal treatment of the seed, but a soilborne pathogen is more difficult to manage. The fungus can survive in the soil for up to 6 years even when no host plant is present, so cultural methods of control such as crop rotation are of little value.

Disease management has focused on identifying resistant cultivars. ICRISAT has identified over 160 resistant varieties, but the pathogenicity of the fungus varies from one agricultural environment to another. The pathogen has been classified into races according to the resistance or susceptibility of individual genotypes to the pathogen in different regions.

In order to exploit the known resistance to *Fusarium*, it is important to understand the mechanism of resistance. In a collaborative study funded by the ODA, NRI and ICRISAT scientists have identified compounds that are present at higher concentrations in the root exudates of resistant genotypes than in susceptible ones.

In laboratory tests, the compounds show strong anti-fungal activity towards *Fusarium* at concentrations equivalent to those found in the resistant genotypes, but not at lower concentrations equivalent to those in susceptible genotypes. Production of these root compounds has been shown to increase on exposure of the root to the pathogen, thus increasing the defensive capability of the root. Scientists have concluded that different levels of these root compounds account for resistance or susceptibility in different genotypes.

This information is valuable as scientists unravel the geographic variation of the resistance. For example, abiotic factors such as fertilizer applications, soil type, and mineral and nutrient levels may influence secondary metabolism (and production of root compounds), and thus expression of resistance.

Another possibility is that the *Fusarium* fungus may vary among different regions. Pathogenic fungi are known to detoxify defensive compounds produced by plants, so metabolic variation among the different races of *Fusarium* may also account for the differences in resistance among genotypes.

No single chickpea cultivar is resistant to fusarium wilt in all agroecological zones. ICRISAT and NRI scientists now understand the mechanism of resistance, which will help them investigate wild species of chickpea to identify more potent sources of resistance to the wilt fungus.

Wild *Cicer* Species Hold Promise. ICRISAT, in cooperation with ICARDA in Syria, has a breeding program to incorporate resistance to stresses into the cultivated chickpea, *Cicer arietinum*. Over 200 accessions of eight wild *Cicer* species have been evaluated for resistance to two diseases (ascochyta blight and fusarium wilt), two insects (leaf miner and seed beetle), cyst nematode, cold, and drought. Resistance was found for all seven stresses. Wild species are the only known sources of resistance to seed beetle and cyst nematode, and higher levels of resistance to fusarium wilt, leaf miner, and cold were found in wild species

When cultivated chickpea (left) is crossed with a wild species (right), their progeny (center) can be more vigorous than either parent.

than in cultivated ones. No germplasm accession of the cultivated species has been found to have genes for resistance to even two stresses; however, many accessions of wild species have genes for resistance to three or even five stresses. Among the wild species, *Cicer bijugum* has the most genes for resistance to several stresses, and *Cicer yamashitae* the least.

Research efforts to transfer genes for resistance to cold and cyst nematode from wild to cultivated species have made good progress over the last five years, and it is expected that in two years the resistance genes will have been transferred.

Interspecific crosses between wild and cultivated *Cicer* species are substantially more vigorous than intraspecific crosses. Encouraged by this finding, selection was made for seed yield in subsequent generations. Yields over 30% higher than these from the best available cultivar have been obtained from succeeding fourth and fifth generations. This work has been strengthened, because it offers a good opportunity to upgrade the genetic potential of seed yield in chickpea.

Introducing Chickpea to Uganda. Southwestern Uganda is a lush, equatorial area with bimodal rainfall, where altitudes range from 1250 to 2500 m asl. Banana is the major crop, covering nearly 40% of the cultivated area, while cereals and legumes occupy another 16 to 20%, either as sole or intercrops. Animal protein has become scarce in Uganda, and beans and peas are important alternative protein sources. Bean production, however, is threatened by aphids and four common diseases.

The first ICRISAT/SWRARP chickpea trials in southwestern Uganda.

As part of its research on farming systems and crop diversification, the South West Region Agricultural Rehabilitation Project (SWRARP), funded by the World Bank, asked ICRISAT to provide chickpea cultivars for trials at different altitudes. Sixteen cultivars were sown in May 1993 at five locations following the short rains, and a further six locations were sown after the long rains in November.

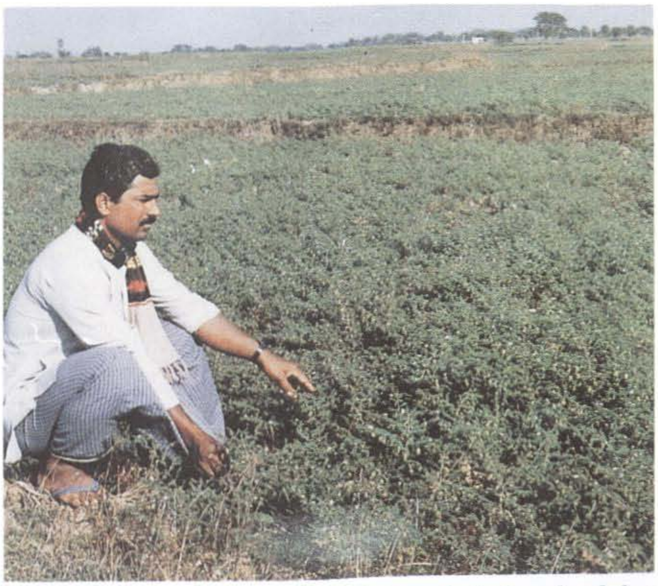
Chickpea is particularly adapted to well-drained soil with good initial moisture in a relatively cool climate—the slopes of southwestern Uganda are probably ideal. Even though chickpea has not previously been grown in Uganda, some of the pathogens that cause its diseases are already present in the country. Luckily, much of the

ICRISAT material has good resistance to the most damaging of these diseases. The first trials yielded about 2.5 t/ha which was nearly 1 t more than that from comparable nonirrigated plots in India following good rains. The trials at higher altitudes were more successful than those on the lower slopes, where soils are far more acidic.

The ICRISAT breeder collaborating with SWRARP was pleasantly surprised when Ugandan researchers distributed seed of selected varieties grown in the first trials to several farmers. Other farmers in the area were curious about the crop and how it could be cooked. They readily sampled Indian foods prepared from chickpea which the ICRISAT breeder had brought with him, and were eager to obtain seed to sow in their own fields. SWRARP staff are playing a leading role in introducing chickpea to Uganda by growing it on their own farms and in kitchen gardens. ICRISAT will continue to collaborate with Ugandan researchers as the evidence builds to show the potential of chickpea for use in various cropping systems in southwestern Uganda.

The Bangladesh Barind. ICRISAT has been collaborating with chickpea researchers in Bangladesh since 1978 by providing breeding material to the national pulses program for evaluation and selection. Over the years, several high-yielding varieties derived from ICRISAT material have been released through collaboration with the Bangladesh Agricultural Research Institute and the Crop Diversification Programme (CDP), which is funded by CIDA.

In a collaborative venture that aims to broaden a local production system, ICRISAT, national researchers, and CDP are introducing chickpea to the Barind region, the northwestern part of Bangladesh where 0.8 million ha typically remain fallow following a rainy-season rice crop. Early indications are that chickpea could be a major crop in this area if it can be sown while enough moisture remains in the soil after the rice harvest. In 1992/93, chickpea was sown on over 1100 ha, and some farmers' plots had yields over 2.5 t/ha. ICRISAT will continue to provide technical support and training for chickpea research and development in this driest region of Bangladesh.



Chickpea can produce crops in Bangladesh on land that was previously left fallow.

Revitalizing Groundnut Production in Africa

Groundnuts are important for many reasons: they are an excellent source of both protein and cooking oil; the oilseed cake and haulms are used as animal feed; and as a traded commodity they earn foreign exchange. African farmers—many of them women—grow groundnut on about 5 million ha, annually producing about 3 million t with an estimated value of US$ 1 billion.

Trading groundnuts in West Africa.

African groundnut production needs to be both stabilized and increased to improve the nutritional status of rural communities, to increase cash income, and to improve household food security. As part of their continuing efforts to prioritize research, ICRISAT scientists have recently conducted surveys in Swaziland and Malawi to identify the production constraints most worthy of attention there.

In Malawi, groundnut production has declined over the past few years. Baseline data were collected to establish the constraints which affect groundnut farmers, and researchers quantified the economic losses due to early leaf spot disease, the most serious and destructive disease of groundnut in the SADC region. In collaboration with our sister institute the International Food Policy Research Institute (IFPRI) and Bunda College of Agriculture, Malawi, economists estimated that eliminating yield losses in this major crop due to early leaf spot disease could potentially increase export earnings by 46%.

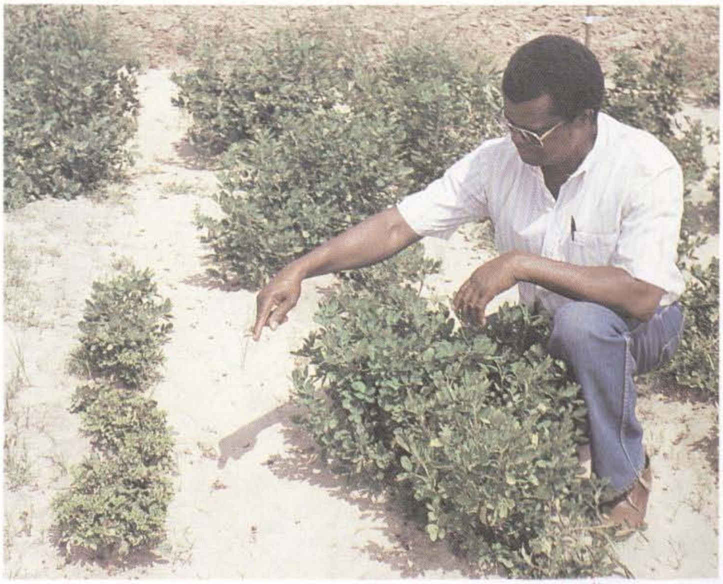
Rosette. In many areas, yields of groundnut crops are severely reduced by insects and diseases. Rosette disease is the most destructive virus disease of groundnut in Africa, and is apparently restricted to regions south of the Sahara and off-shore islands. Although this disease occurs sporadically, it is estimated to cause crop losses valued at approximately US$ 50 million annually. When the disease occurs in epidemic proportions, an entire crop may be wiped out. In Nigeria, groundnut was an important commercial crop until drought and rosette epidemics devastated production in the early 1970s. Less severe epidemics in the 1980s caused a shift from groundnut to cereal production, but farmers now have renewed interest in reviving groundnut within their farming systems.

There has been good progress in western Africa and in the SADC region in breeding medium-duration (130–140 days) virginia-type groundnuts with rosette resistance. NARS have bred and released resistant varieties in both regions.

However, only about 10% of the groundnut-growing areas of southern Africa have a rainy season long enough to support medium-duration cultivars. It is important, therefore, to develop rosette-resistant cultivars suitable for drier environments. Some germplasm resistant to rosette disease has been identified, but progress in breeding rosette-resistant short-duration groundnut varieties has been slow for two main reasons—the range of early-maturing resistance sources is limited, and it is difficult to transfer resistance from medium-duration sources to adapted short-duration cultivars.

At the SADC/ICRISAT Groundnut Project in Malawi, scientists have developed an effective field screening method to evaluate germplasm for rosette resistance. During the 1992/93 cropping season, they screened 1374 groundnut genotypes and identified 12 early-maturing, rosette-resistant spanish types—9 from Burkina Faso, 2 from Nigeria, and 1 from Senegal—that originated from western African NARS breeding programs many years earlier. Another resistant genotype from Argentina was identified in 1993, and an inter-specific derivative produced at IAC that was identified two years earlier is still maintaining its resistance to rosette.

ISC scientists collaborate with the Institute of Agricultural Research (IAR) in Nigeria, the SADC/ICRISAT Project, and local NARS. IAR screens for rosette resistance, while NARS scientists evaluate segregating populations and progenies. IAR has developed its own improved lines which will be entered in a regional rosette resistance nursery. This is a positive change in the flow of germplasm—spillover from a NARS center of strength to other NARS in the region, with ICRISAT at ISC acting as a conduit. In 1993, both the segregating and advanced breeding lines together with inter-specific hybrid derivatives

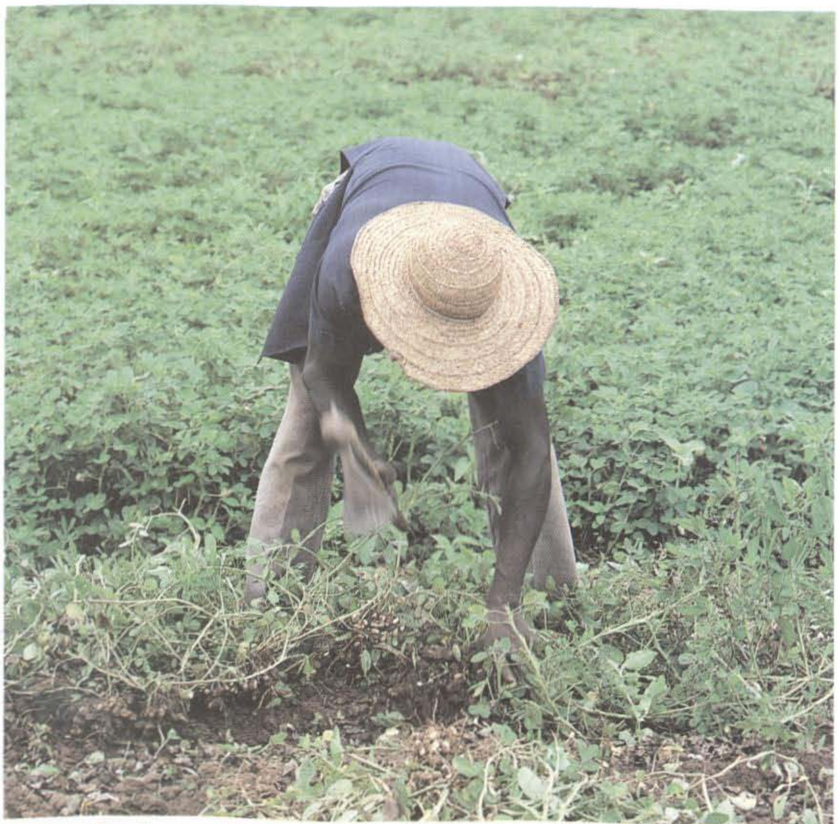


Rosette virus disease reduces yields by stunting and killing plants.

from ICRISAT were screened at IAR, and rosette-resistant lines identified. Adding new sources of rosette resistance is an important contribution to widening the genetic base of rosette resistance in groundnut. In southern Africa, the first rosette-resistant, short-duration breeding lines were evaluated for yield in 1993/94, and will enter farmer trials during 1994/95.

Further expand the genetic base to scientists in the Cellular and Molecular Biology Divison at IAC are crossing cultivated groundnut with wild species identified as resistant to groundnut rosette virus and groundnut rosette assistor virus by collaborators at the Scottish Crop Research Institute (SCRI) and exploring the possibility of inducing resistance by introducing the viral coat protein gene into groundnut.

Improved Varieties. The importance of groundnut to the economy of western African countries and its value as a food crop justify the need for more productive varieties. Progress has been made in varietal development—several new groundnut varieties are being tested in farmers' fields, and a few have been released.



Improved cultivars can boost groundnut production in Africa.

In the Gambia, ICGS (E) 52 was found promising in national trials and was advanced to on-farm testing. Production is higher than traditional varieties because early maturation allows it to escape drought. The adoption rate of this new variety is expected to be high because groundnut is very important to the Gambian economy. In a regional trial conducted in seven countries, variety ICGV 86015 yielded 20 to 40% more than the local varieties and averaged 1.65 t of pods/ha across locations. This variety has shown stable performance since its introduction to the region in 1989.

Spreading the Word

Exchanging information is crucial to ICRISAT's success—our research is of little value if the results are not communicated to our collaborators and clients around the world. Similarly, our research cannot be conducted in isolation. If it is to be targeted effectively, we need to receive information from our collaborators, farmers, consumers, and stakeholders.

Human Resource Development. During the last two decades, over 2400 individuals from 89 countries have participated in ICRISAT training programs at IAC alone. As capabilities of our NARS partners increase, the emphasis of our training has changed. Many NARS now provide excellent general scientific training, with ICRISAT's contribution limited to some course materials and occasional training of trainers.

ICRISAT has therefore moved to offering specialized courses based on demand, and continues to provide facilities and guidance, in conjunction with recognized universities, for agricultural researchers from many countries working toward postgraduate degrees. Several of such courses were held in 1993.

In-service trainees learning to cross sorghum.

Specialized Training Courses 1993

Course	Location	Attendees from
Pigeonpea Production and Processing	Sri Lanka	Sri Lanka
Detection of Seedborne Groundnut Viruses	IAC	Bangladesh, India, Nepal, Sri Lanka
Chickpea Pathology	IAC	Egypt, India, Myanmar, Sudan
Agroclimatology	IAC	Sudan, Syria, Yemen
Legumes Production	Myanmar	Myanmar
ICAR/ICRISAT Training Workshop on Plant Genetic Resources	India	Bangladesh, China, India, Indonesia, Malaysia, Myanmar, Nepal, Philippines. Sri Lanka, Thailand, Vietnam
Statistics and Data Management	Mali	Burkina Faso, Mali
Exploitation of Crop Growth Models	ISC	Burkina Faso, Mali, Niger
Experimental Methods and Data Collection for Agroforestry Technicians	ISC	Burkina Faso, Mali, Niger, Senegal
Training Workshops On-farm Research	Zimbabwe Malawi	Zimbabwe Malawi
Strengthening NARS Capabilities for On-farm Research	Namibia	Namibia
Effective Written Communication	Zimbabwe	SADC NARS
Pesticide Spraying Methods	Malawi	Malawi
Groundnut Disease Diagnosis and Management	Malawi	Malawi
Traveling Workshop on SATCRIS	Myanmar Sri Lanka Thailand	Myanmar Sri Lanka Thailand
Bioassay Techniques for Monitoring Insecticide Resistance	IAC	India
Installation and Operation of Portable Rainout Shelters and Drip Irrigation Systems	IAC	India
International School on Subtropical Climates and their Evolution	ISC	Algeria, Benin, Burkina Faso, Chad, Congo, Côte d'Ivoire, France, Guinea, Kenya, Mali, Mauritania, Niger, Rwanda, Senegal
Improvement of Agricultural Systems	Niger	Burkina Faso, Cameroon, Chad, Guinea, Niger, Senegal
Elements of Soil Physics	ISC	Burkina Faso, Chad, Cameroon, Mali
IITA/SPALNA/INRAN/ICRISAT Equipment Maintenance Training Course	ISC	Niger, Nigeria, SPALNA members

Networks. Networks are one of the mechanisms by which we exchange information and technologies with our research collaborators in specific regions. During 1993, the Asian Sorghum Research and Development Network merged with the Cereals and Legumes Asia Network (CLAN). This merger will streamline the interaction among NARS and ICRISAT scientists, which includes meetings, exchange of germplasm, collaborative research, and copublication of useful material in local languages.

Discussing groundnut experiments

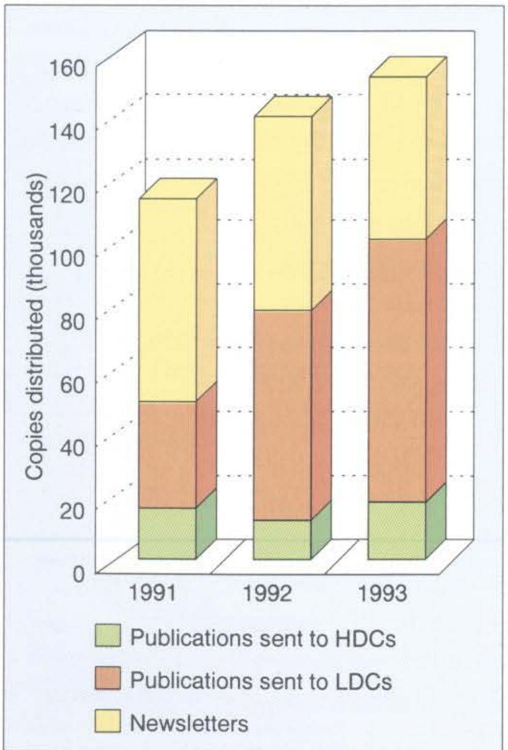
Information Management and Exchange. ICRISAT's publishing, information management, and related services are handled predominantly, but not exclusively, within the Corporate Office. These services represent important links to our collaborators, other stakeholders, and the world scientific community. Since its inception, ICRISAT has considered it essential to collaborate not only in research and technology transfer, but also to ensure that NARS scientists have access to the latest scientific, technical, and socioeconomic information to support their work.

Semi-Arid Tropical Crops Information Service (SATCRIS). ICRISAT maintains an authoritative database on worldwide literature pertaining to our mandate crops and their production systems. Each month, through a selective dissemination of information (SDI) service, information on new literature is provided to over 400 subscribers in 52 countries. Profiles of these subscribers' research interests reside in our user database so that the information sent each month is customized to their needs. Since many subscribers do not have direct access to adequate libraries, the SDI outputs are often the only source of current awareness for many of them. We also provide copies of listed papers or articles on request, enabling users to remain abreast of developments in their disciplines.

During 1993, 19 new subscribers from nine African countries and 27 from four countries in Asia were added. To increase awareness of the value of these services, workshops for researchers, academics, librarians, and other potential users were held in Myanmar, Sri Lanka, and Thailand. At these workshops we described the database, how it is assembled, and the SDI, literature search, and document delivery services ICRISAT provides. ICRISAT's activities and plans in the field of electronic publishing were also covered. Subsets of the SATCRIS database covering the areas of interest to the research stations in the three countries were provides to key libraries as part of the workshops. These subsets will be used on microcomputers in the NARS, and will be provided with periodic updates.

Computer-based Diagnostic Systems. In a project partially funded by the International Development Research Centre (IDRC), Canada, we are developing a prototype diagnostic system on groundnut crop protection. This is being based on 'Expert System' software designed to mimic the knowledge and inference capabilities of human experts in narrow problem areas. If well developed, such computer-based diagnostic systems can encapsulate the knowledge and deductive capabilities of many human 'experts' from multiple locations. Such systems are potentially particularly useful in agriculture, since researchers, extension agents, and farmers are scattered over remote geographical locations and may have limited access to direct expert advice. Once developed, a diagnostic system can be distributed to any potential user having access to microcomputers.

The prototype system under development will be both diagnostic and advisory—it will help identify insect pests and diseases and nutritional problems, and will recommend crop management strategies for prevention and control. Intended users are NARS scientists, extension workers, and university researchers throughout the world's groundnut growing regions where English is an appropriate language. Given the necessary funding, a French language version will be subsequently made available.



Scientific publications. During 1993 ICRISAT published 62 new titles.

We also copublished four Plant Material Descriptors of our mandate crops with our sister center, the International Plant Genetic Resources Institute (IPGRI). One of these, *Descriptors for Chickpea*, was also copublished with ICARDA.

Due to high demand, over 21 000 copies of 18 titles originally published prior to 1993 were reprinted. In 1993, over 101 000 copies of new and existing publications were distributed; 30% more than in the previous year. The popularity of two identification

Plant breeders in Vietnam using Descriptors for Groundnut *copublished by IPGRI and ICRISAT.*

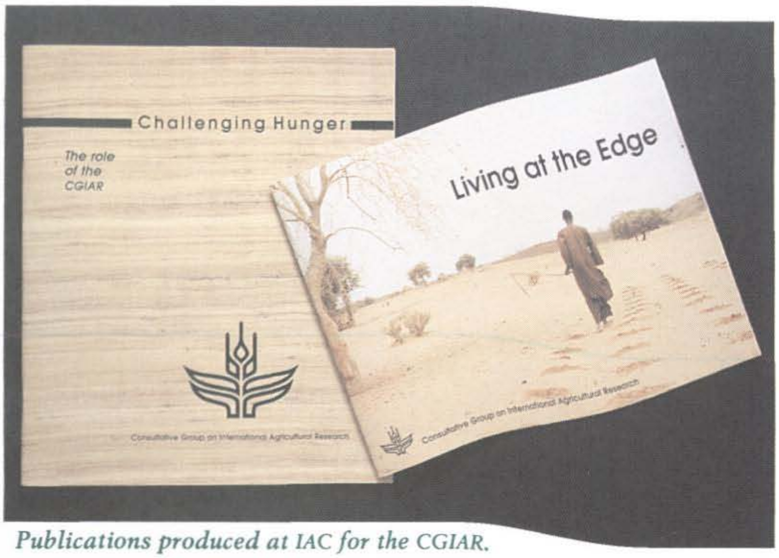
handbooks, published in five Asian languages contributed significantly to this increase.

We distributed over 50 000 copies of ICRISAT newsletters during 1993. These included the general interest newsletter (*SAT News*), and the three international legumes newsletters that provide a global coverage of chickpea, pigeonpea, and groundnut research activities. Over half of the articles in the legumes newsletters are written by NARS scientists. In 1994 the International Chickpea and Pigeonpea Newsletters will be merged, and we will co-publish the International Sorghum and Millets Newsletter with the Sorghum Improvement Conference of North America and the University of Georgia.

Publishing is a measure of scientific achievement. In a recent article which evaluated the publication productivity of the international agricultural research centers, ICRISAT ranked highly by several measures—number of publications, number of articles in refereed journals, publications per scientist, and refereed journal articles per scientist.

ICRISAT's widespread collaboration extends to its publishing effort. Over the life of the Institute, over 550 external conference papers authored by ICRISAT scientists have been published. Of over 1500 refereed journal articles that have been published, nearly 25% have been co-authored by non-ICRISAT scientists.

In addition, nearly 1800 internal conference papers have been published by ICRISAT, with over half of them written by collaborating scientists from developing countries and another 7% co-authored with ICRISAT scientists. Since ICRISAT publications are known to be reviewed and edited to international standards, research results from NARS collaborators published by ICRISAT are indexed, abstracted, and made available to a global audience.



Publications produced at IAC for the CGIAR.

Public Awareness. ICRISAT maintains an active public awareness program so that policymakers, donors, and other stakeholders are informed about the value and progress of our work. In addition to our scientific publishing, we produce materials which describe our work for nonscientific audiences.

The Indian television service featured ICRISAT's work on IPN in groundnuts.

ICRISAT hosts special events to explain our work to donors, the media, and the public. During 1993, for example, two important receptions were held in New Delhi. One was attended by Ambassadors, High Commissioners, and senior representatives of our donor nations and agencies based in India. Another meeting was held for the benefit of representatives of the international media.

Articles about ICRISAT and its work regularly appear in many languages in newspapers and other periodicals around the world, and the work of the Institute is featured in radio and television broadcasts, including four broadcast by the BBC in 1993.

Two recent public awareness publications were produced on behalf of the CGIAR—*Challenging Hunger* and *Living at the Edge*.

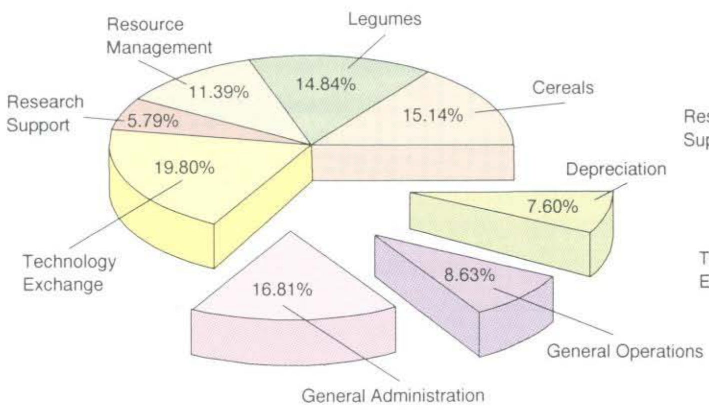
Challenging Hunger explains the basic role of the CGIAR–its mission, its accomplishments, and its aspirations. *Living at the Edge* is a more focused document that explains the Group's response to a specific suggestion that arose from the Earth Summit in Rio de Janeiro: namely, to address the urgent need for coordinated action to reverse the degradation of potentially productive drylands. ICRISAT, concerned as it is with research on marginal areas, was a logical choice to prepare a publication covering the CGIAR's Desert Margins Initiative.

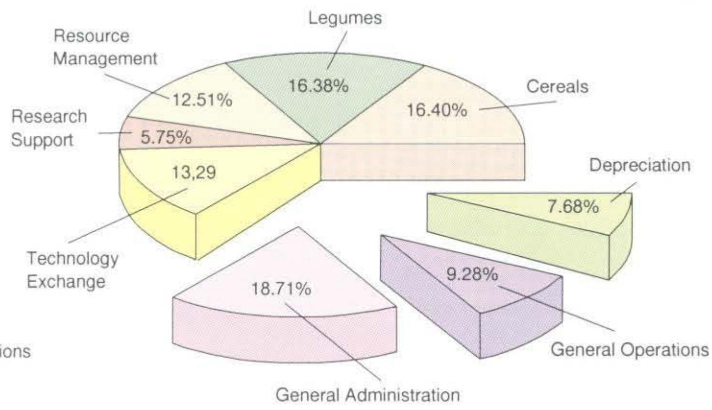
ICRISAT-specific public awareness publications include *ICRISAT Anew*, a brochure describing how the Institute has restructured itself to face its changing challenges, and *ICRISAT Now*, this alternative to an annual report.

Donor Contributions (Core and Complementary)

	(US$ millions)	
	1993	1992
African Development Bank	0.7	0.6
Asian Development Bank	0.4	0.4
Australia	0.7	0.7
Austria	0.2	–
Belgium	0.2	0.2
Canada/Canadian International Development Agency/ International Development Research Centre	2.4	3.2
European Economic Community	2.1	2.3
Finland	–	0.2
France	0.3	0.4
Germany/Bundesministerium für Wirtschaftliche Zusammenarbeit/Deutsche Gesellschaft für Technische Zusammenarbeit	2.8	3.0
India	0.1	0.1
Italy	–	0.4
Japan	4.1	3.4
Netherlands	0.4	0.5
Norway	0.7	0.8
Sweden	0.6	0.9
Switzerland	1.6	1.9
United Kingdom/Overseas Development Administration	1.3	1.6
United Nations Development Programme	1.5	1.7
United States Agency for International Development	5.8	8.1
University of Hohenheim, Germany	0.2	0.2
World Bank	5.1	3.9
Other	0.2	0.1
Total	31.4	34.6

Resource Allocations (Core and Complementary)



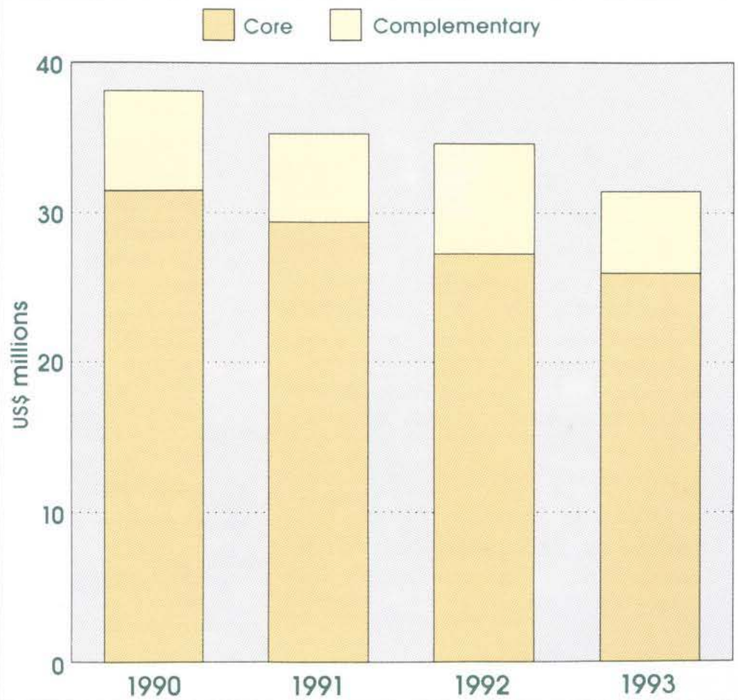


Balance Sheet

	(US$ thousands) 1993	1992
Assets		
Cash and short-term deposits	12 800	14 438
Accounts receivable	4 995	7 204
Inventories	711	761
Prepaid expenses	367	354
Long term investments	3 850	–
Fixed assets – net	50 951	50 726
Total Assets	73 674	73 483
Liabilities		
Accounts payable and other	3 775	1 420
Accrued salaries and benefits	4 881	3 836
Payments in advance from donors	2 669	6 054
In-trust funds	43	169
Capital		
Undesignated	54 914	56 152
Designated	7 392	5 852
Total Liabilities and Capital	73 674	73 483

Audited financial statements are available on request.

Funding



The decline in funding indicated here is compounded by the effects of inflation.

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The listings presented here indicate the staff member's name, country of origin, designation, and work location. It should be remembered that research conducted in any one country can generate benefits throughout the SAT and beyond, and that ICRISAT scientists are working on global problems irrespective of their work location.

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J Sai Prasad, *India*, Manager (Software), **India**

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N Vidyalakshmi, *India*, Scientist, **India**
S M Virmani, *India*, Principal Scientist, **India**
S P Wani, *India*, Scientist, **India**

Awards and Distinctions

N K Awadhwal received the Best Paper Award at the 28th Annual Convention of the Indian Society of Agricultural Engineers.

P Prakash Babu was elected a Fellow of the Indian Society of Genetics and Breeding.

S C Gupta was appointed Adjunct Professor in the Department of Agronomy, University of Nebraska, Lincoln, USA.

M P Haware received the M S Pavgi Award–1992 from the Indian Phytopathological Society.

ICRISAT received an honorary diploma on the occasion of Empresa Brasileira de Pesquisa Agropecuaria's 20th Anniversary.

The **ICRISAT Report 1992** won the Agricultural Communicators in Education Silver Award.

L K Mughogho was honored at the First Crop Science Conference for Eastern and Southern Africa, in Kampala, Uganda.

A K Murthi was elected a Fellow of the Royal Microscopical Society, UK.

Y L Nene delivered the Dr N Prasad Memorial Lecture at the inaugural session of the Indian Society of Mycology and Plant Pathology. He was the Chief Guest and delivered the Convocation Address at the 5th Convocation of the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. He delivered the Glenn Anderson Lecture jointly sponsored by the Canadian and American Phytopathological Societies at the International Congress of Plant Pathology in Montreal, Canada. Dr Nene was elected President of the Society of Mycology and Plant Pathology, Udaipur, Rajasthan for 1994, was admitted as an Honorary Fellow to the Indian Society of Plant Pathology, and received the Indian Society of Pulses Research and Development Award for 1994.

P V Vara Prasad received the Potash and Phosphate Institute of Canada - India Program Gold Medal for the Best Thesis during the 27th Annual Convocation of Andhra Pradesh Agricultural University.

H C Sharma was elected Chief Editor of the *Indian Journal of Plant Protection* for 1993/94.

S B Sharma was awarded the Rothamsted International Fellowship.

K B Singh was elected a Fellow of the Indian National Academy of Agricultural Sciences.

Umaid Singh was named Scientific Adviser (Food Science) to the International Foundation for Science, Stockholm, Sweden.

M V K Sivakumar joined the Boards of Editors of *Agricultural and Forest Meteorology* and *Field Crops Research*.

R P Thakur became a Fellow of the American Phytopathological Society.

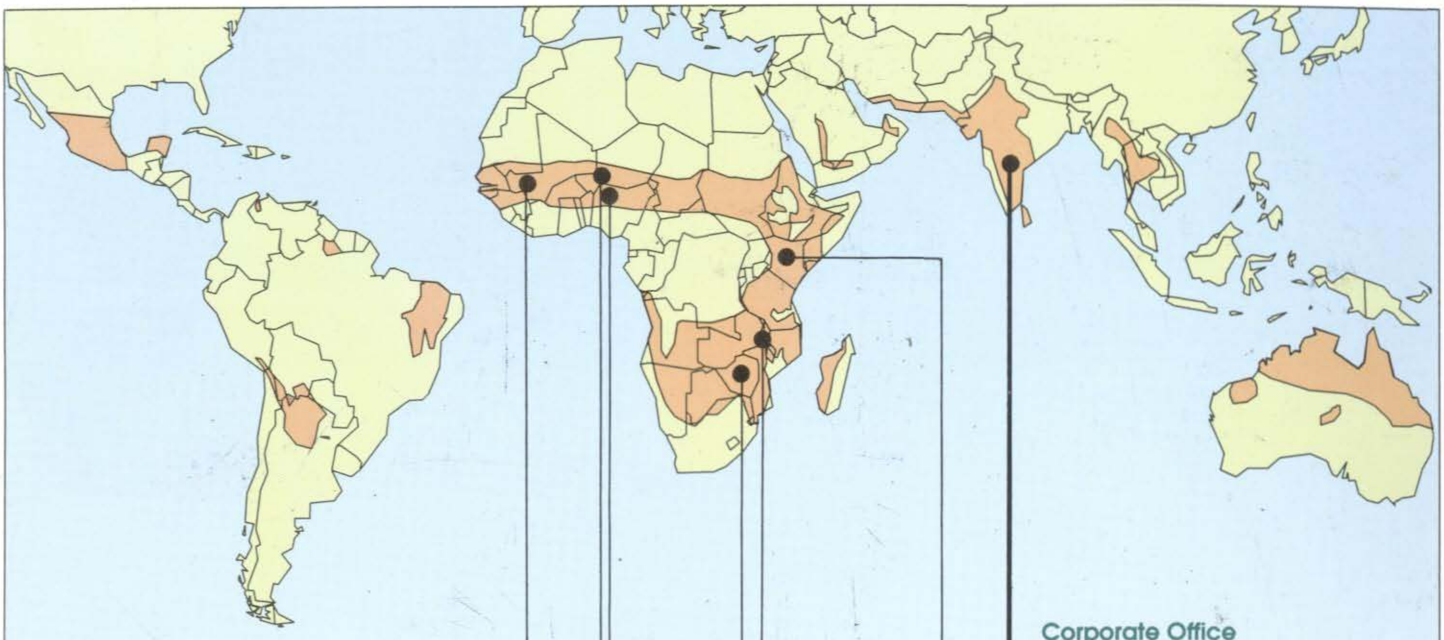
M M Verma and **Jagdish Kumar** won the Outstanding Research Paper Award from the Crop Improvement Society of India.

S P Wani joined the Editorial Board of the *Indian Journal of Microbiology*.

ADB	Asian Development Bank (Philippines)
AfDB	African Development Bank (Côte d'Ivoire)
APAU	Andhra Pradesh Agricultural University (India)
asl	above sea level
AUA	Alemaya University of Agriculture (Ethiopia)
BMZ	Bundesministerium für Wirtschaftliche und Entwicklung Zusammenarbeit (Germany)
CDP	Crop Diversification Programme (Bangladesh)
CEC	Commission of the European Communities
CGIAR	Consultative Group on International Agricultural Research (USA)
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CIDA	Canadian International Development Agency
CIMMYT	Centro Internacional de Mejoramiento de Maïz y Trigo (Mexico)
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (France)
CLAIS	Comisíon Latinoamericano de Investigadores en Sorgo (Guatemala)
CLAN	Cereals and Legumes Asia Network
CRIDA	Central Research Institute for Dryland Agriculture (India)
EC	European Community (Belgium)
FAO	Food and Agriculture Organization of the United Nations (Italy)
GIS	geographic information system
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Germany)
IAC	ICRISAT Asia Center (India)
IAR	Institute of Agricultural Research (Ethiopia and Nigeria)
IARC	international agricultural research center
IBPGR	International Board for Plant Genetic Resources (Italy)
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas (Syria)
ICRAF	International Centre for Research in Agroforestry (Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre (Canada)
IER	Institut d'économie rurale (Mali)
IFAD	International Fund for Agricultural Development (Italy)
IFDC	International Fertilizer Development Center (USA)
IFPRI	International Food Policy Research Institute (USA)
IITA	International Institute of Tropical Agriculture (Nigeria)
ILCA	International Livestock Centre for Africa (Ethiopia)

Acronyms

INERA	Institut d'études et de recherches agricoles, (Burkina Faso)
INTSORMIL	USAID Title XII International Sorghum/Millet Collaborative Research Support Program (USA)
IPGRI	International Plant Genetic Resources Institute (Italy)
IPM	integrated pest management
ISC	ICRISAT Sahelian Center (Niger)
ISPA	Indo-Swiss Project Andhra (India)
KARI	Kenya Agricultural Research Institute
LASIP	Latin American Sorghum Improvement Program
LGP	length of growing period
MTP	Medium Term Plan
NARS	national agricultural research systems
NGO	non-governmental organization
NORAGRIC	Norwegian Centre for Internaional Agricultural Development
NRI	Natural Resources Institute (UK)
ODA	Overseas Development Administration (UK)
OAU	Organization of African Unity (Ethiopia)
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
QDPI	Queensland Department of Primary Industries (Australia)
ROCAFREMI	Réseau ouest et centre africain de recherche sur le mil (Niger)
SACCAR	Southern African Centre for Cooperation in Agricultural Research (Botswana)
SADC	Southern African Development Community (Botswana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Nigeria)
SAT	semi-arid tropics
SATCRIS	Semi-Arid Tropical Crops Information Service
SCRI	Scottish Crop Research Institute (UK)
SDI	selective dissemination of information
SMIP	Sorghum and Millet Improvement Program (Zimbabwe)
SWRARP	South West Region Agricultural Rehabilitation Project (Uganda)
TAC	Technical Advisory Committee of the CGIAR (Italy)
UN	United Nations
UNDP	United Nations Development Programme (USA)
UNEP	United Nations Environment Programme (Kenya)
Unesco	United Nations Educational, Scientific, and Cultural Organization (France)
USAID	United States Agency for International Development
WANA	West Asia North Africa



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