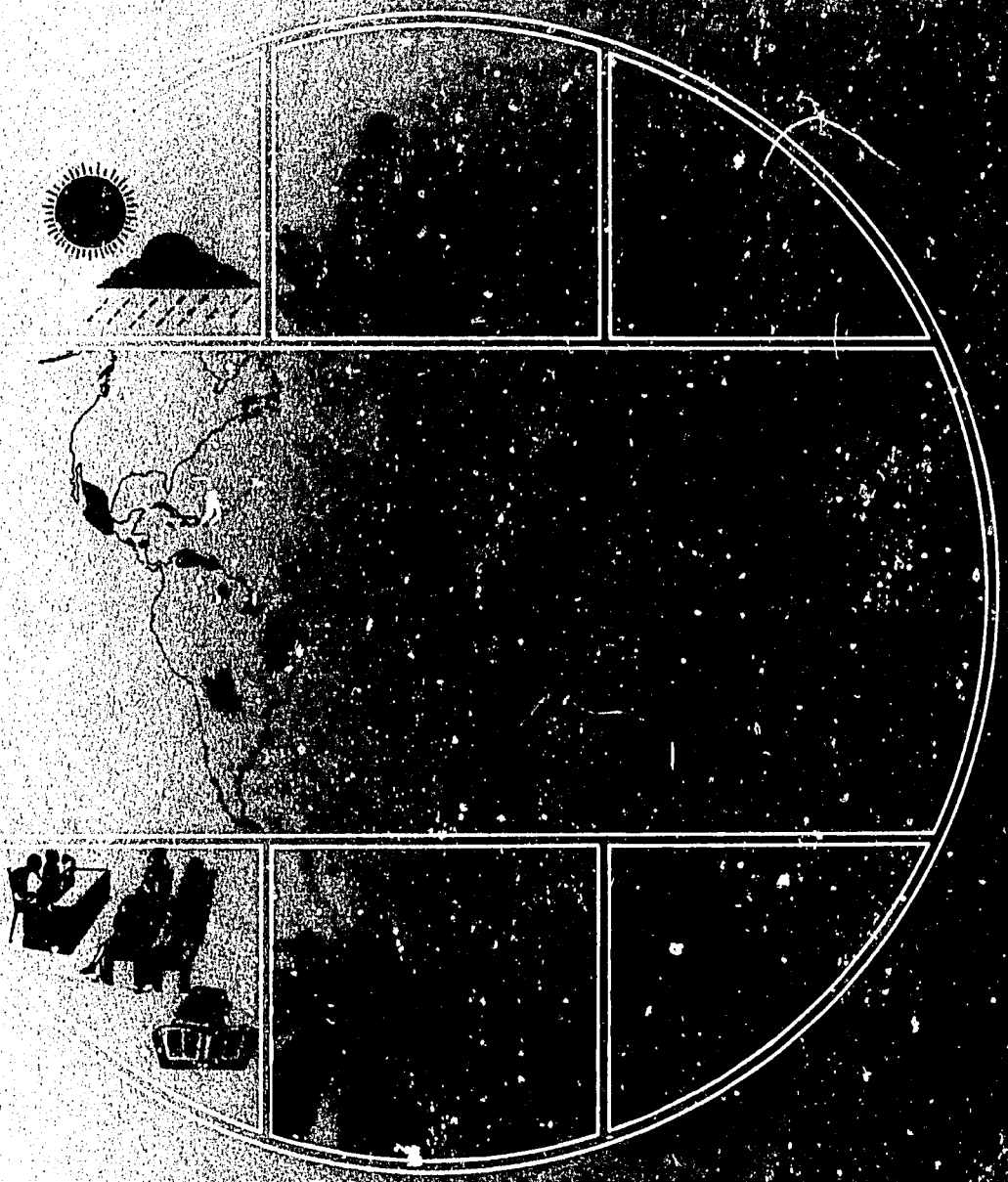
Challenge and Response 1972 to 1982



International Crops Research

ISSUED ON THE OCCASION OF ICRISAT'S
TENTH ANNIVERSARY CELEBRATION, 1982

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is one of the 13 nonprofit scientific educational institutes supported by donors through the Consultative Group on International Agricultural Research (CGIAR). Financial aid for ICRISAT's operations and research during its first decade came from the following countries and organizations.

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ICRISAT: CHALLENGE AND RESPONSE 1972—1982

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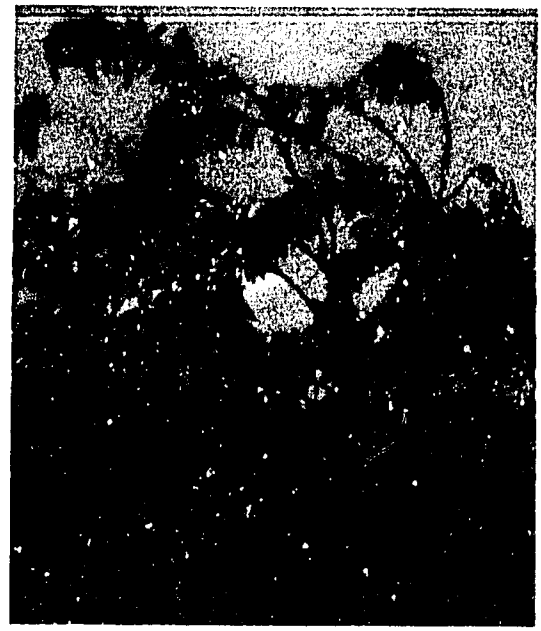

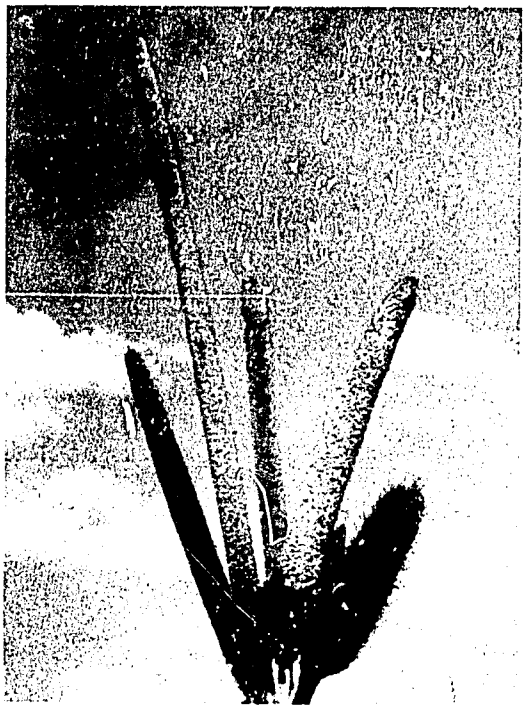

ICRISAT's five mandate crops, shown clockwise from top left: sorghum, pigeonpea, chickpea, groundnut, pearl millet.

About ICRISAT

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- The Southern African Development Community (SADC) Secretariat has signed up to be a Regional Center for Semi-Arid Tropics and Sub-humid lands in the SADC region.
- The Indian Ministry of Foreign Affairs has approved an open leasing of the assets of ICRISAT-Hyderabad to institutes in the developing countries.
- The Independent Inspection Committee for the Consultative Group on International Agricultural Research (CGIAR) has recommended the establishment of a Regional Institute in Sub-Saharan Africa.
- The El Salvador Ministry of Agriculture [illegible] recognition for the ICRISAT Germplasm [illegible]
- Sudan has released one of our [illegible] variety [illegible]
- Ethiopia has released an ICRISAT sorghum line [illegible]
- India has [illegible] release to farmers a cultivar [illegible] market WC-C75.

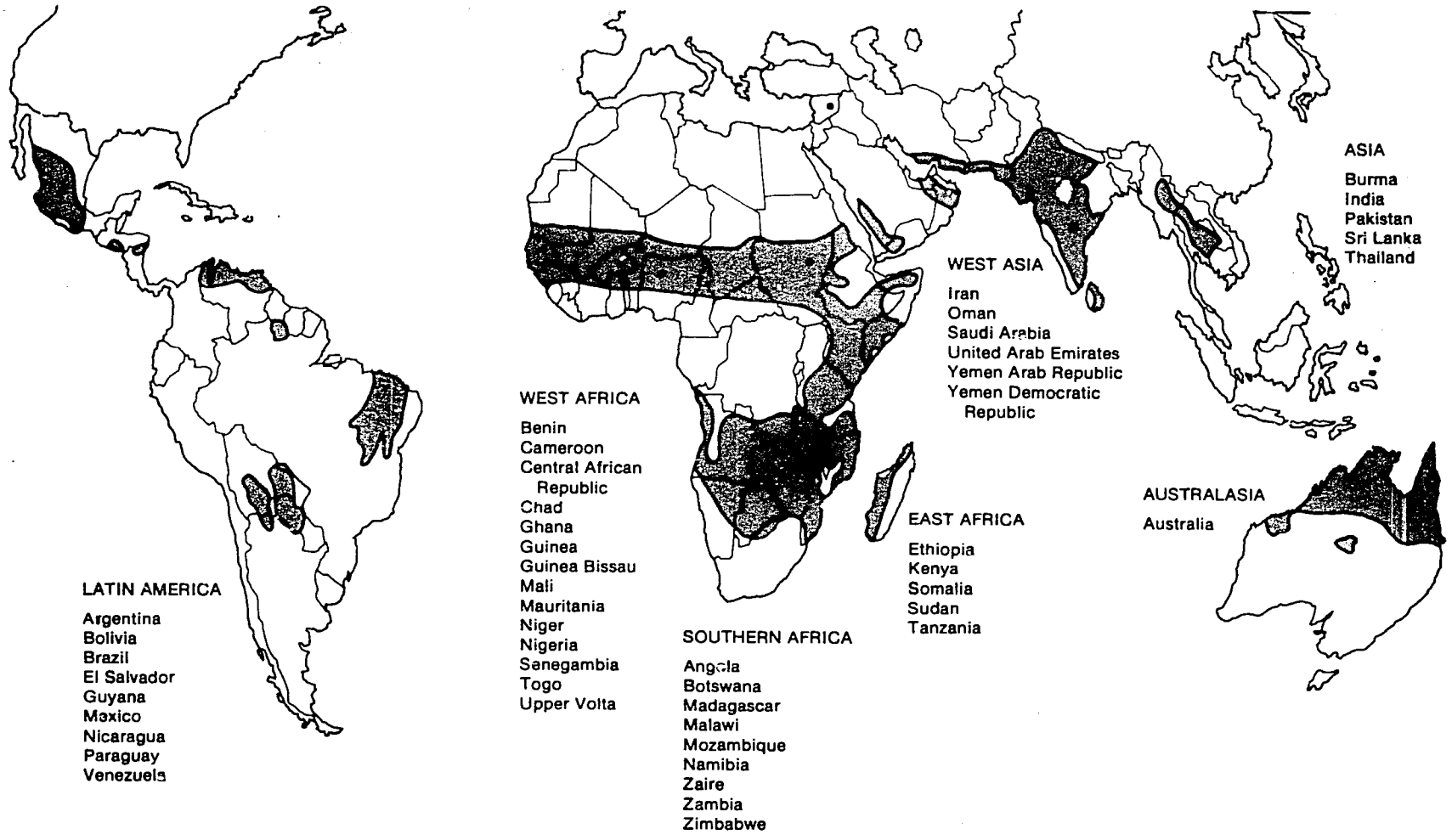


Figure 1. Developing and developed countries with semi-arid areas covered by ICRISAT's mandate (shown in yellow). The red squares indicate the position of ICRISAT Center in India and the Sahelian Center in Niger, and the red dots the location of collaborative research stations with resident ICRISAT staff.

The Institute

For generations the world's rural poor in the semi-arid tropics have lived with the insecurity of unpredictable harvests and the fearsome threat of periodic food shortages. Today scientists are bringing sophisticated research talents to the task of boosting food production and upgrading the quality of life of subsistence farmers and their families.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), with headquarters at Patancheru near Hyderabad, India, has for the past decade been developing cultivars (cultivated varieties) of crops and improved systems of farming to assist small farmers in the developing world. Our tenth anniversary is an appropriate time to look back at some significant things we have accomplished, to consider their potential impact on world agriculture, and to attempt to peer into the future.

ICRISAT carries out research in what has been termed "the hardest end of the research spectrum: rainfed farming in the semi-arid tropics." The agreement establishing the Institute stressed the need for improvements in sorghum, pearl millet, pigeonpea, chickpea, and was later amended to include groundnut. It urged development of higher-yielding varieties and more productive farming systems. It also called for analyses of social and economic limitations to adoption of new methods and for spreading information about the benefits of this research as widely as possible.

ICRISAT's activities currently are directed at 49 countries wholly or partially in the semi-arid tropics (the SAT: Fig. 1). About 750 million persons live in these semi-arid regions.

Main entrance to ICRISAT Center at Patancheru, India.

Financial support for the Institute runs to about $14 million annually for the core operational budget. It has been provided by 34 different countries, international agencies, and private foundations listed on the inside front cover. Without their staunch support, our work could not continue.

ICRISAT's five mandate crops were carefully selected because of their importance in the semi-arid regions of Asia, Africa, and Latin America and to the subsistence farmers who live there. The SAT produces more than 55% of the world's sorghum, 95% of the pearl millet, 90% of the chickpea, 96% of the pigeonpea, and 67% of the groundnut.

Sorghum and pearl millet are the two main cereals on which villagers in the SAT depend for their daily supply of food. Together they rank first in order of caloric intake in Africa and third in Asia. Sorghum is also popular in Latin America, often as an insurance crop when maize production fails. Sorghum and pearl millet can withstand prolonged periods of dry weather and limited rainfall and demand for both is increasing faster than production.

Chickpea and pigeonpea are high in protein content and are sometimes eaten with cereals. They are among the most popular food legumes in the SAT and an important part of the diet of millions of people. Groundnut, with 25% protein and 50% oil, is both a food crop and one of the world's major sources of edible oils. It also provides some cash income to the small farmer.

Except for groundnut, the ICRISAT-mandate crops are all subsistence foods and anything from half to all of the crop each year is consumed by the farmer and his family. In addition to food, the crops often provide animal fodder, thatch, and fuel.

International Cooperation

Though the main ICRISAT Center is at Patancheru, in Andhra Pradesh, India, the Institute also has scientists stationed in Mexico and seven African countries, with a new Sahelian Center under development in Niger. Its scientists work closely with colleagues interested in the same crops and similar farming techniques in countries outside the SAT, such as Canada, China, Lesotho, the Netherlands, Nepal, the Philippines, United States, United Kingdom, Japan and West Germany. In Syria, two ICRISAT scientists work with staff of the International Center for Agricultural Research in the Dry Areas (ICARDA).

The ICRISAT Sahelian Center is regional headquarters for our research effort in West Africa. It is the major base for our work on pearl millet and eventually will include groundnut and farming systems associated with these crops. It also provides administrative and logistical support for our sorghum work in the region. In neighboring Upper Volta a research team is stationed at Kamboinse, the main agricultural station of the Voltaic Ministry of Higher Education, and is testing the product of local sorghum and pearl millet varieties crossed with improved cultivars.

Our West African efforts have been singled out for praise by the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), which serves seven West African countries subject to severe food shortages. CILSS expressed its satisfaction with ICRISAT's cooperative proposals for research and training in millet and sorghum at a joint meeting of the Organization of African Unity (OAU) and the Semi-Arid Food Grain Research and Development (SAFGRAD) program in March 1980.

Later that same year, the Southern African Heads of State Summit Conference called on ICRISAT to set up a research center in Botswana. The conference noted that a majority of the people in their countries (Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe) are dependent on farming for their livelihood, but few of the countries are self-sufficient in staple foods. Food security, they said in asking for our help, is a major

challenge both nationally and regionally.

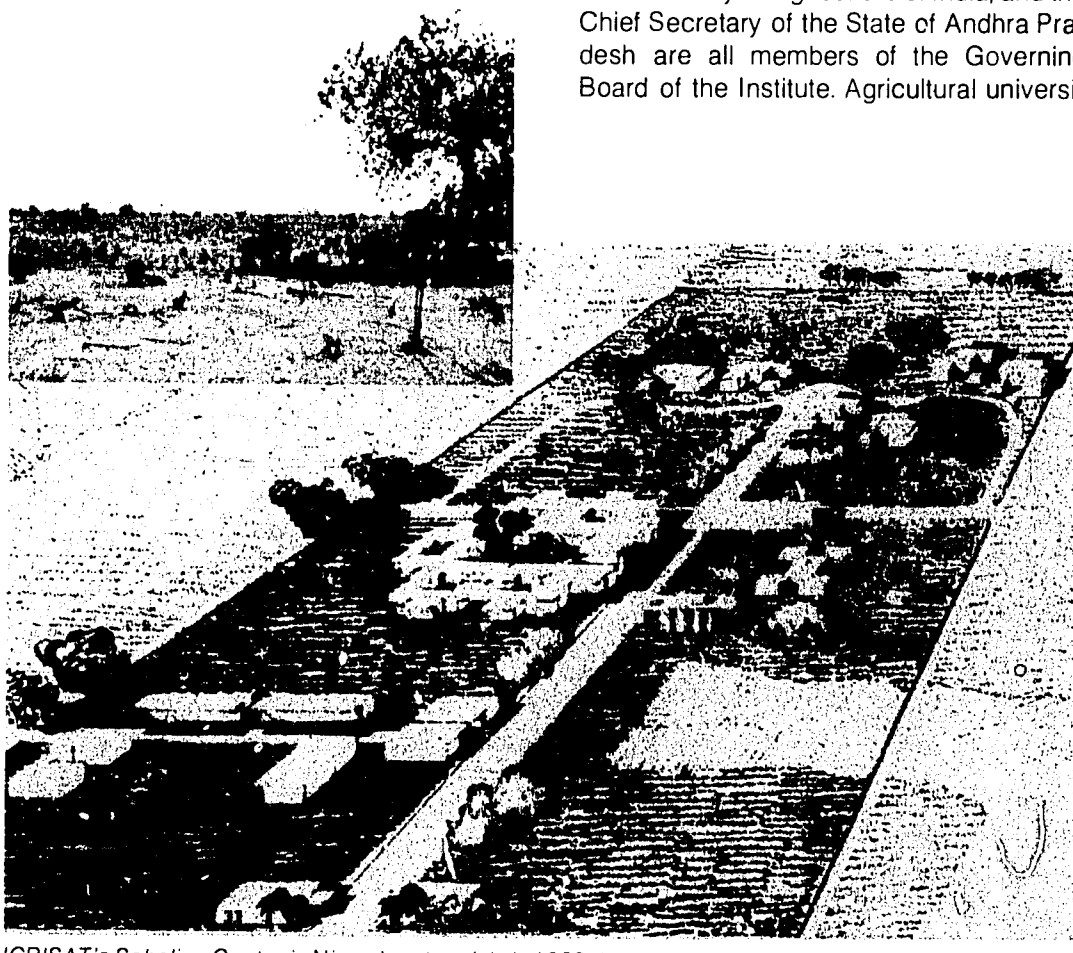
Other research in Africa is carried out in Mali, Nigeria, Senegambia, and Sudan, and we recently signed an agreement with the government of Malawi for regional work under which two ICRISAT groundnut scientists will be stationed at Lilongwe.

Discussions are under way with the governments of Thailand and Sri Lanka for cooperative work there, and we also have been cooperating with national programs in Australia, Kenya, and Latin American countries. Research possibilities in Southeast Asia, including a grain legume project, are currently under consideration.

Collaboration with National Programs

In our research on crop improvement and seeking better farming methods, we work closely with national agricultural programs in SAT countries. Initially a major part of our cooperative research has focused on southern Asia, where nearly two-thirds of the villagers and small farmers of the semi-arid countries are concentrated.

We have worked particularly closely with the Government of India, which provided the land with both black and red soils for our Center at Patancheru. The Director General of the Indian Council of Agricultural Research, the Secretary of Agriculture of India, and the Chief Secretary of the State of Andhra Pradesh are all members of the Governing Board of the Institute. Agricultural universi-



ICRISAT's Sahelian Center in Niger. Inset, as it is in 1982; below, as it is planned to be when completed.

ties have helped us develop cooperative research stations at Anantapur, Bhavanisagar, Dharwar, Gwalior, and Hissar. At the latter four, on a south-to-north axis, we collaborate on crop improvement in climates different from that at Patancheru but similar to those in parts of the African, Asian and Latin American SAT. Similarly, we have recently designated a network of communities in different climatological subzones in Upper Volta and Niger for socioeconomic studies.

Interaction with national programs and exchange of breeding materials are a continuous process. However, research that culminates in release to farmers of improved and tested cultivars takes years of patient work. Figures 2a and 2b show that development of a variety or hybrid may take 6 years; 5 more years may pass before national field trials

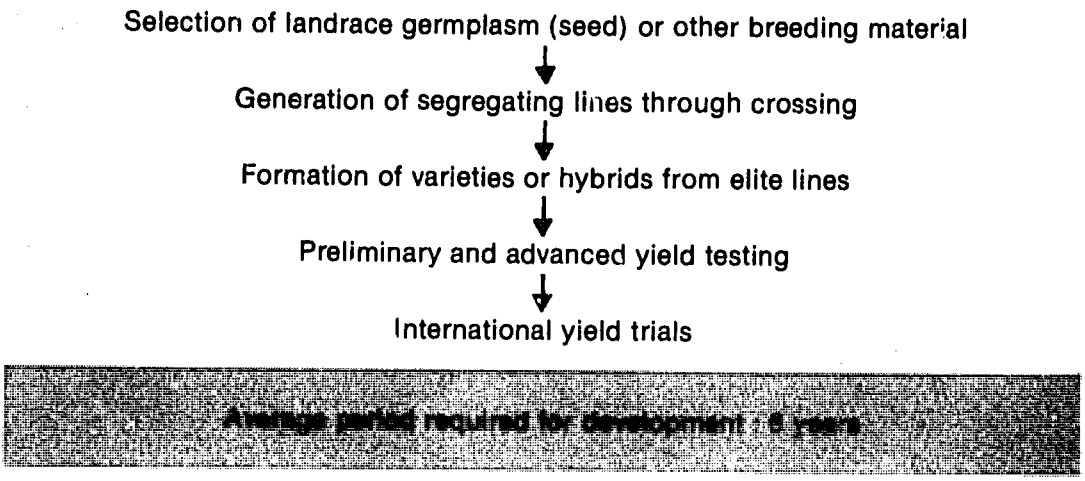


Figure 2a. Stages in the development of crop varieties or hybrids at ICRISAT.

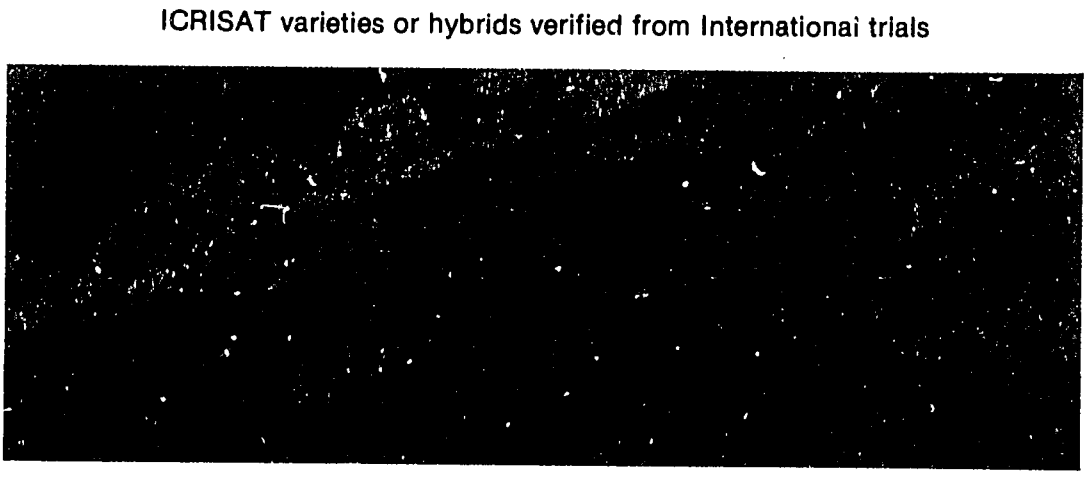


Figure 2b. Steps in testing ICRISAT varieties or hybrids by national programs before final release to farmers.

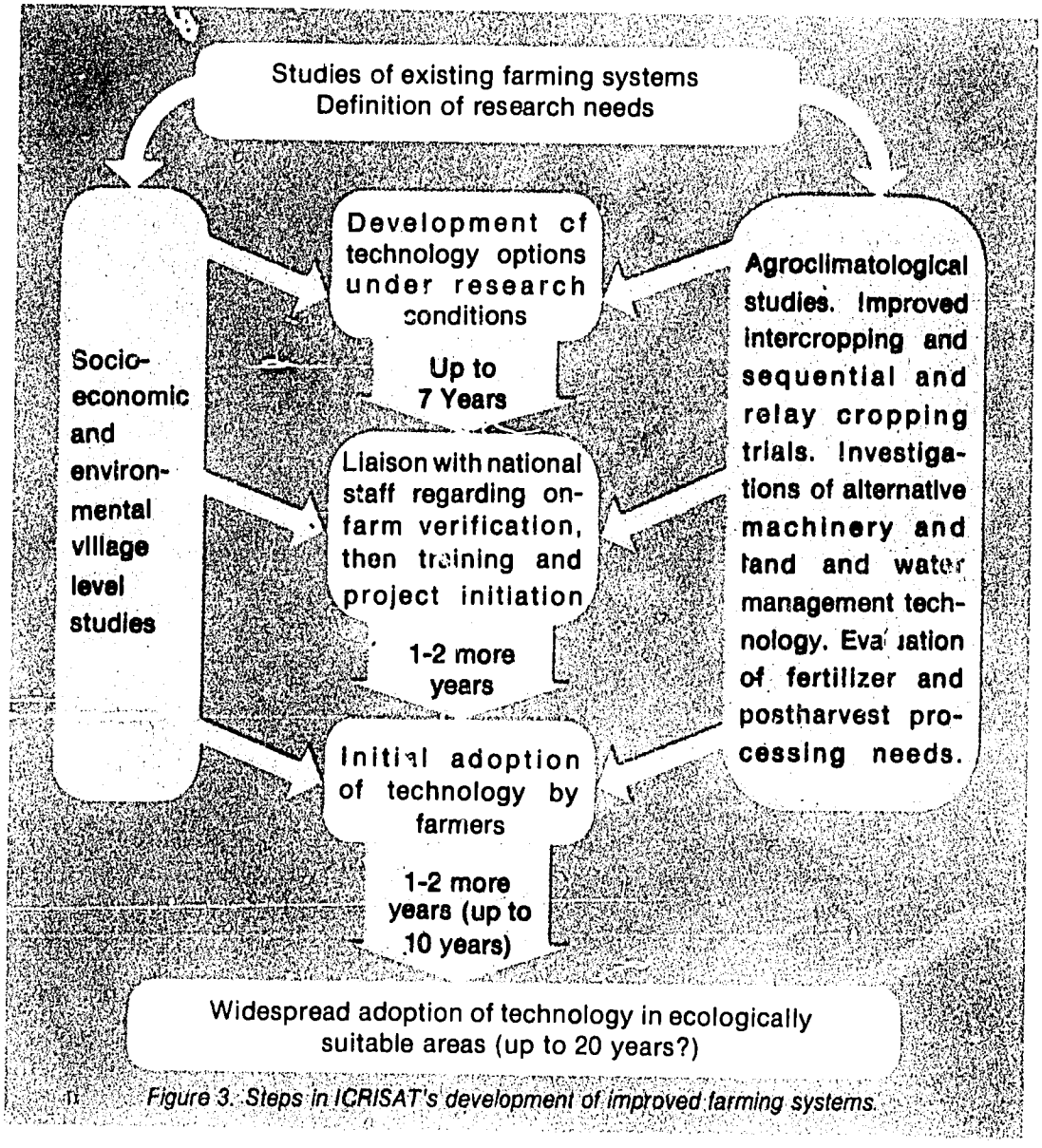


Figure 3. Steps in ICRISAT's development of improved farming systems.

are completed and the farmer gets new seed. Breeders or extension staff may skip a stage to speed up the procedure.

Breeding materials that are exchanged during initial trials mean that some tangible benefits of ICRISAT research reach breeders well before final release.

Changes in farming systems and water management also take many years to develop (Fig. 3). In our experience 3 years or more may go into baseline environmental and cropping studies and social surveys before the first steps of a new technology can be worked out to suit specific local conditions. Another 4 years may pass as we try improving various methods of cropping, developing alternative machinery, and devising more efficient means of managing land and water resources.

Only after these careful advanced prep-

arations are we ready to begin trying our recommended improvements in an actual farming situation. During the first years of on-farm verification, ICRISAT's scientists may be intimately involved with national programs; gradually our participation will decrease. In the end, 10 years will probably have passed between the definition of the problem and the first on-farm adoption of those parts of the research that have worked out in actual practice and been accepted by the farmer. Observations will continue, modifications may take place, and understanding and acceptance of the methods by the farming community may take several more years.

Crop improvements and land management systems are dynamic activities. We must meet new challenges as we make new and often unanticipated discoveries. Our new methods probably will bring new problems—for instance, vigorous weed growth in better-drained soil, demands for more workers at peak seasons, or reduced prices because of increased production.

The Semi-Arid Tropics: Challenge and Response

"Better nutrition is vital to human development," the World Bank said in its 1981 World Development Report. "In both low- and middle-income countries, the poorest urban and rural groups are chronically undernourished. The worst affected are those living in rural areas where agricultural production fluctuates widely," it continued, adding that seasonal variations in food supply and crop failures because of bad weather and pest infestation lead to shortages that are "an ever-present threat to life."

Today the danger of global food deficits has declined, but national and local shortages are still a potential problem, the Bank noted, pointing out that strategies for increasing agricultural production and alleviating rural poverty must be "specific to local conditions" and "adaptive research" is a clear priority.

The Bank speaks directly to the challenges ICRISAT is facing. Our five mandate crops are vital to the subsistence farmer and projects directed at him are "just as cost-effective a way of increasing food supplies as projects designed to benefit commercial farmers and frequently . . . even more efficient," the report said.

Higher total caloric intake is the most important way to improve nutrition, as various studies have shown. Our research on high-yielding, pest- and disease-resistant cultivars seeks to provide the added margin in a world where 30 of the 36 low-income countries show a daily per capita intake less than the amount required to maintain health.

The farmer in the SAT is caught up in a cycle from which he has been unable to break free. He lives in a risky physical environment, where crop yields are low. As a result he cannot afford to acquire healthy and resistant seeds and appropriate implements, nor can he consider making changes in the way he farms, which at least give him some measure of protection in bad years. With a small farm and virtually no money, he can't easily improve his lot. Each year he follows the cycle shown in Figure 4: harsh environment, low yields, limited inputs for the next season, no credit, and back again, still as poor as ever. Many other factors—land tenure, marketing, food and pricing policies,

credit, education, and training—contribute to his problems.

In fact, the farmer can do very little to change the physical environment which keeps him in this cycle of misery. But, as the founders of ICRISAT said, "there is a great need, and an equally great potential and opportunity for the development of scientific technology applicable to this large sector of the world's agriculture which can improve the quantity and quality of their food supplies and their opportunities for a more useful and satisfying life."

In helping the farmer to find that better life, we have identified four areas of challenge toward which ICRISAT's program is aimed. Panels outlined in red describe problems faced by farmers in the SAT, and the subsequent text tells about ICRISAT's response.

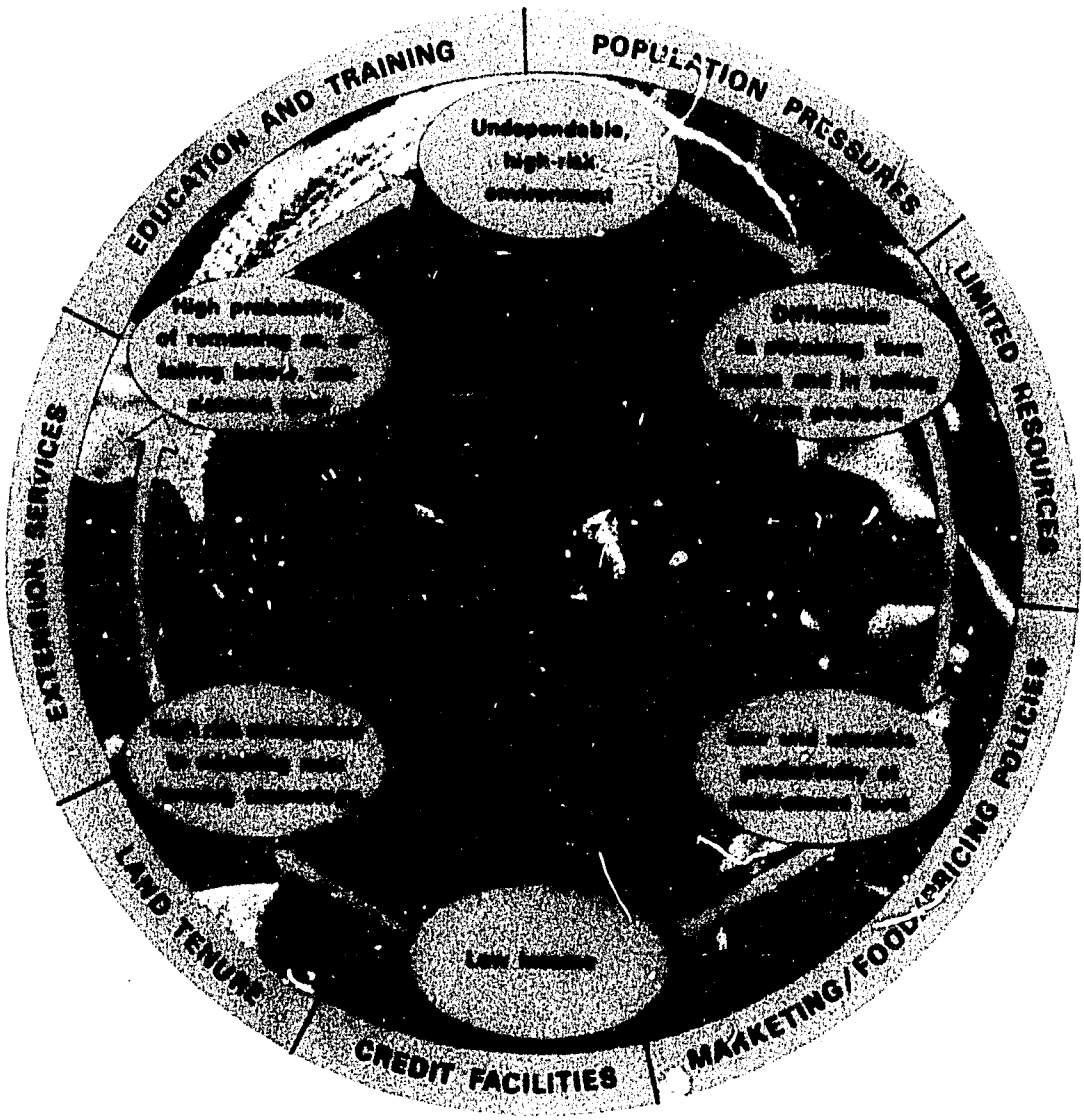


Figure 4. The poverty cycle of the farmer in the semi-arid tropics.

The Environment

Farmers of the SAT raise their crops on some of the poorest, least productive soils of the world. Soil crusting, flooding, erosion, and intermittent droughts are common. Rains may be heavy in one year and light in another.

In the SAT consistently high temperatures lead to loss of moisture through soil evaporation and through transpiration from the crops, thus reducing the effective amount of available water. A third or more of the rain is lost through runoff. Even in the short rainy season of 3 to 4 months, farmers cannot be sure that the seeds they sow will germinate or that the crops will develop and yield normally, because the rains may fail.

Through generations of experience the farmer has learned to cope with this unstable environment and has found crops that are adapted to these areas. But his choices have always been limited and he has few ways of cutting his losses if the rains don't meet his expectations.

At ICRISAT we have studied the length and variability of the growing season, which is a key factor in agriculture in the SAT. We studied timing, amount, and duration of rains throughout the year, its infiltration and storage in the soil, and its release for plant use. We used two mathematical models to permit analysis of the probabilities of establishing successful crops in specific locations, showing the length of the core growing sea-

Scientists in the field at ICRISAT use a steady-state porometer to measure actual water loss (transpiration) through sorghum leaves.

sons and the amount of soil water needed for raising specific crops. Thus our scientists can guide farmers in selecting crops with the correct growing period in relation to moisture in the soil. Such studies are useful in indicating which crops will be successful in intercropping, which will be better for relay or sequential planting. In the case of our work with deep black soils of India, we used modeling to highlight areas of risk associated with dry seeding crops before the rains begin.

Our studies in Mali showed that, when length of the core growing season and water balance are taken into account, a 120-day crop will thrive in Bamako, a 60-day crop at Douentza, and, because the rainy season is so short, there is no suitable crop for dryland agriculture at Gao.

Another project worked out the probability of harvesting sorghum at full grain yield in Hyderabad, India, on the basis of the probable number of rain-free workdays available for harvesting at the end of the growing season. Three full days are required, and harvesting would be no problem with a 130- to 150-day duration crop. A successful harvest would be less likely with a 90- to 100-day crop because of intense August rainstorms that could occur at harvest time.

Socioeconomics

Most SAT farmers have little or no capital, and it is rarely easy for them to obtain loans from banks for equipment and supplies. They and their families do most of the labor, though they may have to hire workers for peak periods. Animal draft power, usually a pair of bullocks, is generally used in Asia, but is less common in Africa. For the farmer who has no animals, hiring them is difficult. Those with produce to sell after they have provided for their families know that markets are widely separated and poorly equipped, and prices are often unpredictable. Whether buying or selling, the farmer is faced with social and economic problems that keep him from enjoying a full life.

The human side of agricultural production calls for expert attention. All the careful work by scientists—the quantification, verification, and replication of studies—is meaningless if the farmer can't get seed because markets are too distant or costs too high, if he doesn't know how to change his farming techniques, or if his family dislikes the flavor of the new sorghum used in their tortillas, chapatis, or ugali porridge.

ICRISAT socioeconomists ask such questions as: Will a farmer risk trying a new cropping technique or is he averse to taking a chance on change? What makes a consumer prefer one sorghum variety over another? Will farmers join in a cooperative arrangement for sharing water or using equipment? If they will, how many can work together in such a group? What about the place of women workers in the labor market?

Our researchers study production and marketing and existing social organization, and coordinate their work closely with colleagues concerned with farming systems and crop improvement. Their work c stantly considers different farming op and helps assure that by the time our tr nologies reach the farmer they will accepted because there is a solid payoff in a better way of life.

At the heart of our operation are Village-Level Studies (VLS) which were launched in 1975 in six villages in different agroclimatic environments in southern India. More recently, additional northern Indian communities and 10 villages in West Africa have been added. In northern India, we collect data in collaboration with agricultural universities.

A trained economic investigator with a rural background and local language fluency works in each of the Indian and African vil- ges and monitors agricultural activities of ple households—10 landless laborers cultivators in the Indian villages. The ators strive for an easy and relaxed relationship with the villagers and monitor existing agricultural systems and conditions for about 3 years before any changes are introduced.

The VLS offer a valuable pool of information and help us adjust our strategies to the "specific local needs" spoken of in the World Development Report of the World Bank.

Lining a new well in Mali. Long-term shared ownership of such facilities for agricultural use is financially and organizationally attractive to small groups of farmers, ICRISAT studies show.

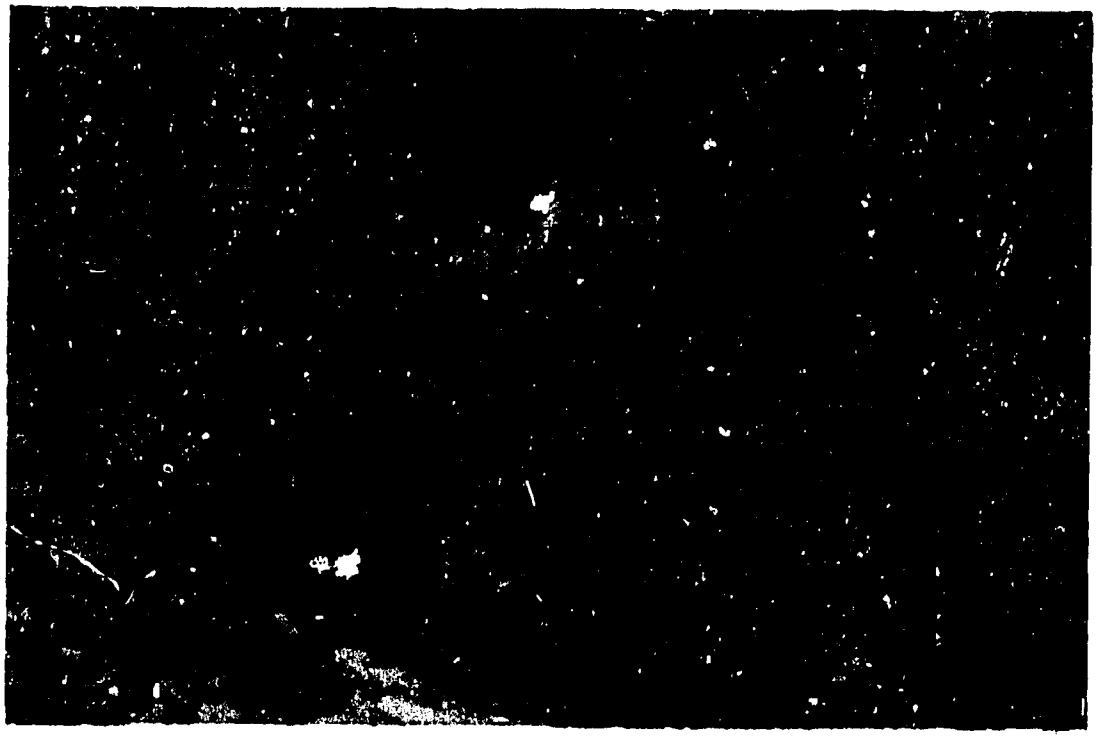
Food grains contribute most of the calories and significant portions of vitamins, proteins, and minerals for farmers and their families in the SAT, but consumption is much too low. To fill critical gaps, breeding strategies for sorghum and millets must emphasize high and stable yield as well as the cooking and eating qualities the consumer values.

Studies on risk aversion indicate that there is little significant difference in the willingness of small and large farmers to take a chance on new cultivars. Therefore, it is more important that all farmers have an opportunity to get good quality seeds at attractive prices than to attempt to breed special low-risk strains aimed at the small farmer.

Because many land and water management improvements are best carried out on a watershed basis rather than on individual farmers' plots, we examined conditions for group action to improve farming systems and agricultural production. The studies suggest farmers will organize and cooperate to improve drainage on a watershed basis. Ponds for recycling runoff on small watersheds seem best suited to use by individual farmers. Facilities for supplementary irrigation, such as wells, can be profitable enough to attract small groups of farmers, since wells can be operated according to simple rules that make long-term shared ownership and use practical.

Tests of the improved sorghum cultivar E 35-1 by ICRISAT economists, agrono-

In the semi-arid tropics, weeding is a major farming activity for women; this mother and her baby live in Senegambia. ICRISAT's improved methods often mean more paid work for women.



mists, and plant breeders in Upper Volta showed that in some years it had yield advantages when grown in highly fertile plots near villages. Using animal traction and better fertilization, we found the cultivar yielded more grain per hectare as well as more produce per manhour of labor. Thus, our higher-yielding varieties, plus our improved farming systems, are appropriate not only in Asia, where land is scarce, but also in countries such as those of West Africa, where labor is in short supply.

Women are particularly necessary workers in the SAT, where weeding is one of their main farming activities. Many are from landless families and they find it difficult to get regular paid employment. As a group they receive the lowest daily wages. New techniques which offer opportunities to women workers are particularly beneficial. In many areas, land is left fallow during the rains and women workers are unable to bring in any income. When a second, rainy-season crop was added in one village, the women were busy with weeding and their incomes increased.

Most farmers in the Indian SAT have a stake in the commercial marketing mechanisms of the country. A survey of 29 sample markets showed that only 22% of the sorghum was sold, whereas 50% was consumed in the home, with the remainder used for wages in kind and for seed. Slightly more pearl millet reached the market, and just over a third of the pigeonpea and 45% of the chickpea were sold, our research revealed.

Studies in India show that convenient access to markets encourages the farmer to sell more and to organize his enterprise better. We have found that when the number of markets is doubled, farmers increase output by 5%; food policies that permit free movement of produce across the country bring an additional gain of 5%. There is a time lag of about 2 years before these benefits are felt. Government-provided services, such as supervised auction trading and telephone facilities in the market center, improve market efficiency and thereby encourage greater productivity.

Crop Improvement

Plant diseases, destructive pests, and parasitic weeds are the relentless enemies of farmers in the SAT. They can decimate whole fields, wipe out a year's production, or merely reduce yields to pitifully low levels. The annual loss is immense, both to individuals and to those nations where food production is never quite adequate.

The seed the farmer uses may be from the best local variety, the same as the farmer's family has been using for generations. It may be fairly resistant to drought, or heat, or able to thrive in poor soil. But it also may be low in yield or its quality may have been damaged during storage. The final product he harvests may lack essential nutrients for his family's diet.

At ICRISAT the aim in crop improvement is increased and stabilized yields. This is a broad description for a program that includes a germplasm bank, breeding for special high-yielding varieties and hybrids, searching for strains resistant to diseases, pests, and parasitic weeds and able to fix more of their own nitrogen. It also means developing food crops able to withstand poor soils and water shortages and extreme heat as well as plants that are adapted to local growing conditions and are acceptable foods.

Genetic Resources

Viable seed and the living vegetative parts of plants carry the germplasm "building bricks" from which scientists construct new varieties and hybrids with enhanced yield and cropping stability.

Scientists seek this germplasm from wild and locally developed varieties (landraces) of crop plants that show specific genetic characteristics which enable the plant to resist the hazards of its natural environment. These characteristics are often found in farmers' traditional cultivars, but many of these are today threatened with extinction.

ICRISAT has accepted world responsibility for germplasm collection and conservation for all five mandate crops and six minor millets. The International Board for plant Genetic Resources has also asked us to serve as a long-term repository for these crops.

Collectors from our Genetic Resources Unit in Patancheru visit SAT and non-SAT countries regularly and work closely with national scientists to collect and preserve as wide a germplasm diversity as possible.

The material is grown in trial plots at Patancheru for initial and detailed evaluation, then the seed is stored in recently completed cold rooms with careful temperature controls to preserve its viability. Plant scientists can draw on this material at any stage in the crop improvement process.

An ICRISAT scientist inspecting pearl millet germplasm under multilocation evaluation close to its place of collection in West Africa.

With the Institute's growing number of collecting collaborators in many countries, it has become possible to undertake germplasm evaluation at or near the place of collection, which permits more accurate evaluation than testing outside the crops' natural adaptation area. We have such pilot-scale projects with local collaboration on pearl millet in Upper Volta and Niger, chickpea in India, and sorghum in Ethiopia.

Collecton started in 1975 and by mid-1982 we had more than 71,600 accessions. Sorghum had the most accessions, followed in descending order by pearl millet, chickpea, pigeonpea, groundnut, and the remaining millets. This is a good start on a vital salvaging operation and we have already sent 161,000 samples to national scientists in 105 countries for use in crop improvement.

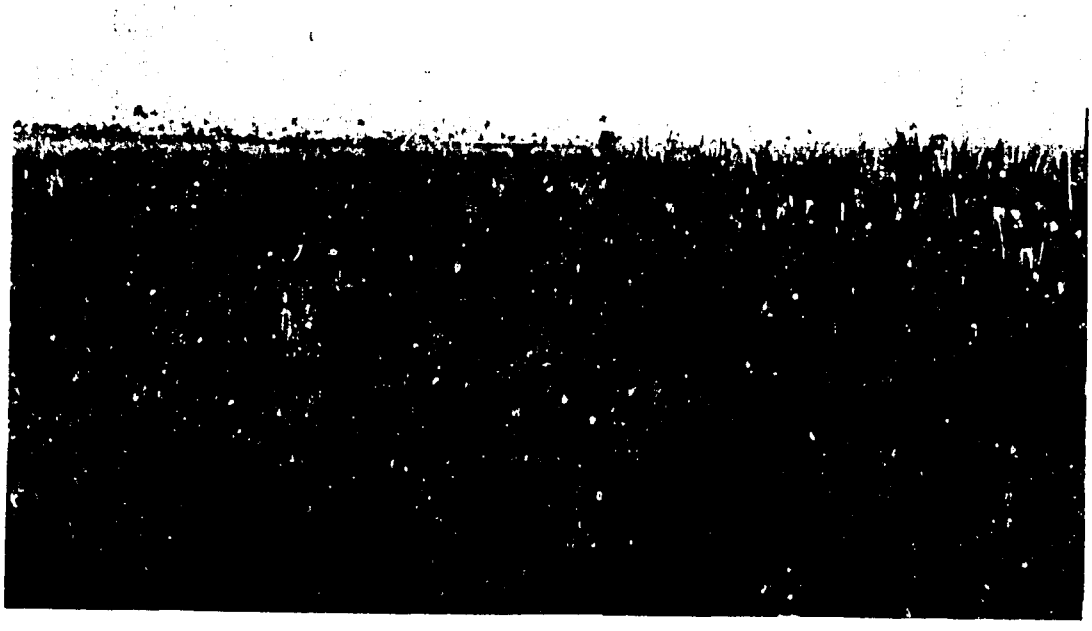
Breeding for Disease Resistance

Disease-controlling sprays are beyond the financial resources and mechanical training of most farmers in the SAT, and experience in the more developed countries has shown that resistance to specific chemical agents can develop. Serious questions about their environmental effects have also been raised.

Research programs for all five of ICRISAT's mandate crops place strong emphasis on developing high-yielding cultivars resistant to some of the pathogens which cause continuing losses, sometimes at disastrous levels. One of ICRISAT's major achievements has been the development of improved and reliable techniques for the routine large-scale screening of the germplasm and breeding lines for their ability to resist disease. We offer national program scientists good, disease-resistant breeding materials and field-tested technologies for further selection, and receive from collaborating scientists valuable information on pathogen variability in many different countries.

Breeding stocks of pearl millet now available for India from ICRISAT all carry high levels of resistance to downy mildew—a

Spores that cause downy mildew in pearl millet blow from the severly diseased row in the center onto the left to challenge plants for resistance and onto the susceptible indicator row on the right, which shows ICRISAT scientists how well their screening system is working.



disease that devastated the hybrid crop in the early 1970s and remains a constant menace to new cultivars.

Integration of these high levels of resistance has been made possible through: (a) the development of an effective large-scale field-screening technique (transferable to all research stations located in millet growing areas), which consistently develops high disease pressure for downy mildew; (b) the availability of good sources of resistance, mostly of West African origin; and (c) cooperative multilocational testing.

Similar principles have been applied to research on the two other diseases of major importance in pearl millet—ergot and smut—and we have identified sources of resistance to both. These are now being incorporated in breeding material, particularly to develop hybrid parent lines. Screening techniques for resistance to all three diseases are fully compatible and we can now, in one generation, subject thousands of plants to downy mildew, then the best individuals to both ergot and smut infection, and finally harvest seed of plants carrying combined resistance to all three diseases.

The example of pearl millet is typical of our research on disease resistance. In the case of sorghum, improved techniques are being developed to screen for resistance to grain molds and downy mildew. White-seeded sorghum lines with reduced susceptibility to grain mold have been developed and we have identified a variety highly resistant to sorghum downy mildew in four continents. With the resources of our germplasm bank at hand, we are striving to develop cultivars of all our crops that will combine resistance with other qualities the farmer wants.

In tackling pigeonpea wilt, which causes annual losses of as much as $113 million in South Asia and Africa, we created "sick" plots by introducing into the soil the fungus that causes the plants to turn yellow and droop. Wilt-resistant lines were found in the field after we planted various germplasm samples there, and we also discovered that wilt incidence was greatly reduced when pigeonpea was intercropped with sorghum.

The most damaging disease of chickpea is *Ascochyta* blight, which regularly causes serious crop losses throughout the Mediterranean region, and in recent years has also markedly reduced crop yields in Pakistan and north India. The screening of ICRISAT's and ICARDA's germplasm collection has resulted in the identification of highly-resistant lines that are being used in breeding and tested for suitability for winter and spring sowing in the ICARDA area.

A high-yielding cultivar of groundnut with adequate combined resistance to leaf spot, rust, and yellow mold is yet to be found. Our scientists are using genetic engineering to introduce sources of resistance we know to exist in the wild *Arachis* species of Brazil, relatives of the cultivated groundnut. Damage to leaves and stems of this crop have serious economic consequences, not only because of low pod yields, but because above-ground parts of the crop are important as fodder.

Breeding for Resistance to Pests

Pests that devour stems and leaves of plants or damage grains and pods are the plagues of the subsistence farmer, who lives in a world where they seem to thrive. Weeds, too, threaten his healthy young plants. Our work with *Heliothis* and shoot [illegible] exemplify the ICRISAT effort to help the [illegible]er in the SAT defeat such formidable en[illegible]s.

Heliothis armigera is probably the most damaging insect pest of the semi-arid tropics, for it feeds upon a wide range of plants, including all the ICRISAT mandate crops. This caterpillar causes particularly severe damage to chickpea and pigeonpea, on

Heliothis armigera *larva feeding on pigeonpea flowers. This pest, called the pod borer, is a threat to all five ICRISAT mandate crops.*

which it is commonly referred to as the pod borer. At ICRISAT we have been searching for plants that are resistant to this pest and have had considerable success, particularly with chickpea. Typical results show only 5% damage in the resistant selections compared with 20% in the currently used cultivar. These selections are now being hybridized by our breeders to produce even greater resistance and to combine this quality with disease resistance, greater yield, and good quality produce. We are studying the chemical basis of the resistance in cooperation with the Max-Planck Institute of Munich.

We are also developing other means of combating insect pests, including use of insect diseases and local and imported parasites which feed upon the pests we study. Another development that may have exciting potential lies in the use of sex pheromones—the scented chemicals exuded by female moths that attract males for mating. We are cooperating with the Tropical Products Institute in London to develop and utilize synthetic pheromones. We now have relatively stable synthetic chemicals that attract many male *Heliothis* moths into our traps. In cooperation with the Indian national program we have set up a network of *Heliothis* pheromone traps across the country, and can now record the seasonal changes in moth populations. As a result, we hope to determine the factors that influence *Heliothis* populations and predict damaging outbreaks of this pest. In the more distant future we may be able to use the pheromones to reduce the incidence of mating and thus cut the numbers of fertile eggs produced by the females.

Shoot fly is a serious insect pest for sorghum growers in India and much of sub-Saharan Africa and Southeast Asia. So far no source material with absolute resistance has been found. The adult female lays single eggs on the undersurface of leaves and the emerging maggots migrate and kill the plant, then feed on the decaying tissue.

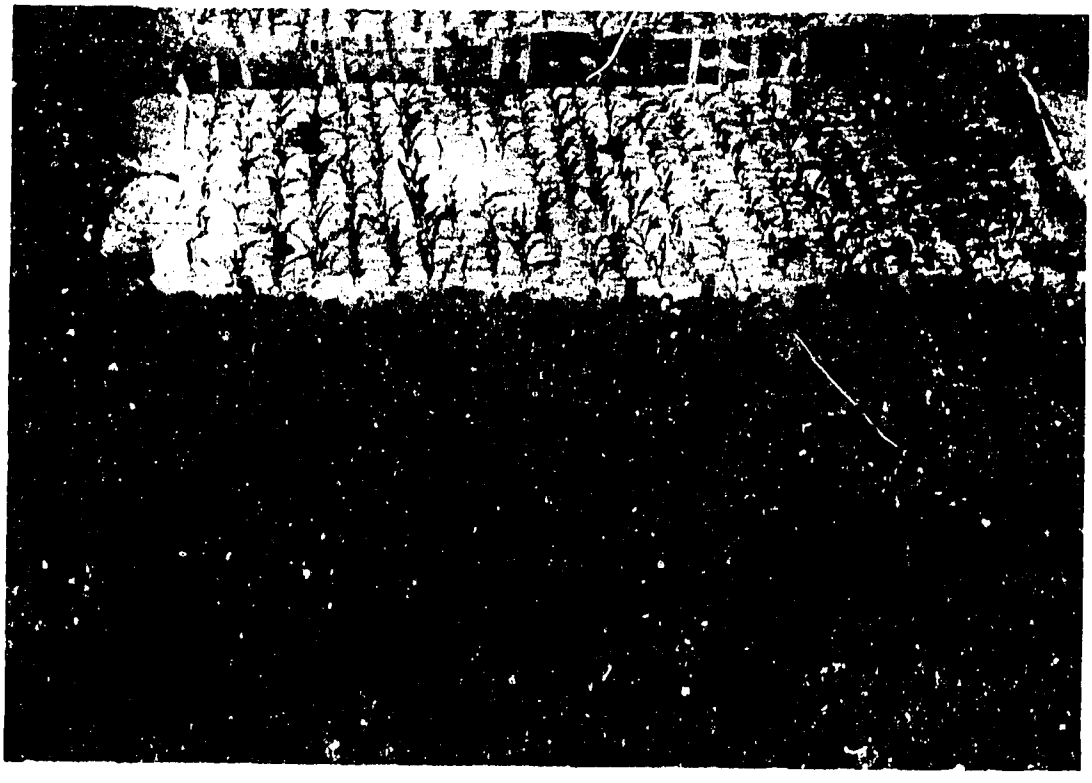
Sorghum cultivars with microscopic hairs (trichomes) on the undersurface of the leaf are generally more resistant to infestation, since the tiny hairs appear to act as barriers to migrating larvae. Plants with a glossy upper surface also seem better able to withstand attacks. By incorporating both of these qualities into plants, we hope to develop a higher level of resistance.

We grew more than 2200 entries from our sorghum shoot fly resistance program at Hissar, northern India, during a severe attack in 1979. In that nursery, 17 of our entries with these two traits suffered less than 30% damage, compared with a local check which suffered 50% damage.

Breeding for Resistance to Environmental Stress

Conditions of extreme environmental stress—drought, high temperatures, soils of

This technique was developed at ICRISAT Center to screen cereal cultivars for seedling emergence under extremes of temperature. It is being used by collaborating scientists in crop establishment research in West Africa.



marginal fertility—are typical of the SAT. The five ICRISAT mandate crops are able to survive these conditions, but yields are generally very low.

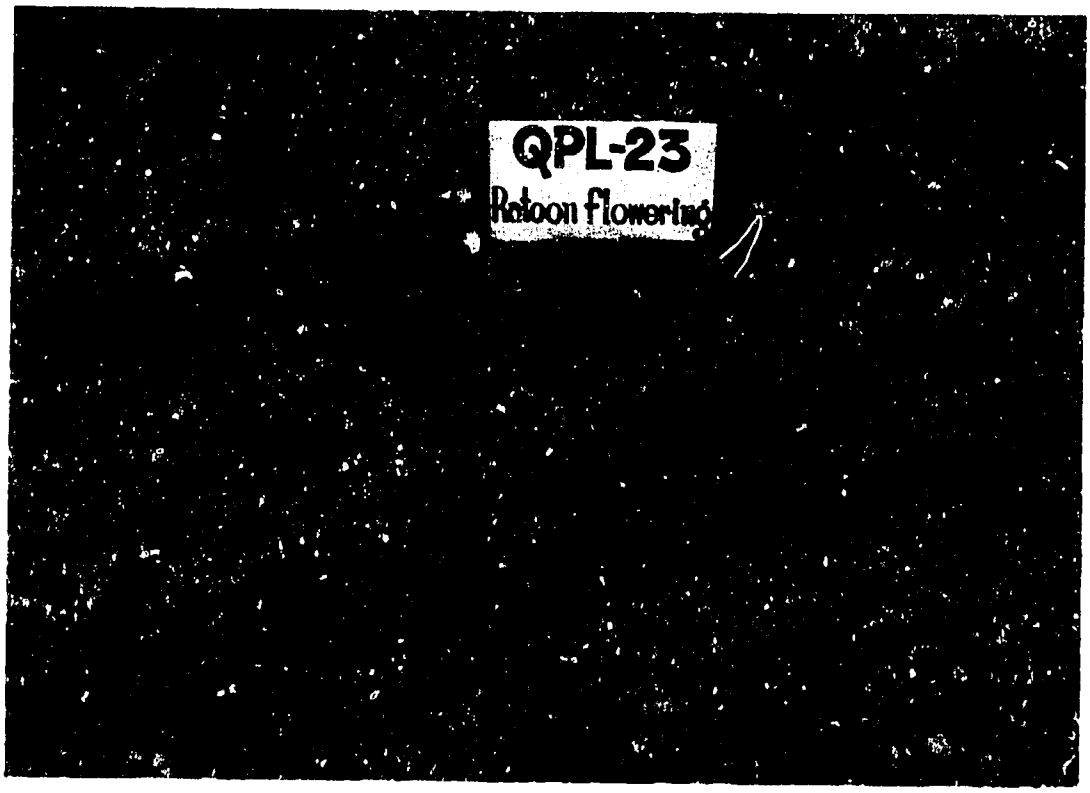
Relatively little is known about the possibility of breeding crops specifically for improved performance under these conditions, since breeders have traditionally used increased yield potential rather than specific adaptation as a way of increasing output.

Major efforts are now going into developing techniques to apply controlled and repeatable physical stresses to sorghum and pearl millet breeding materials. These techniques create both evaluation environments for general breeding materials and selection environments to test the effect of direct selection for tolerance of physical stresses.

Controlled irrigation in the hot, dry season is being used to evaluate the performance of germplasm and advanced pearl millet and sorghum breeding materials under drought stress. We expect field and controlled environment tests to help identify lines with superior ability to emerge and become established in low-moisture and high-temperature conditions.

Pulses—chickpea and pigeonpea—are often grown on marginal land, where stands are patchy and growth poor. Our ICRISAT researchers are currently studying germ-

Early-maturing pigeonpea cultivars ICRISAT is developing for use in northern India fit well into a wheat/pigeonpea sequence and also provide food, fuel, and nitrogen residues to enrich the soil.



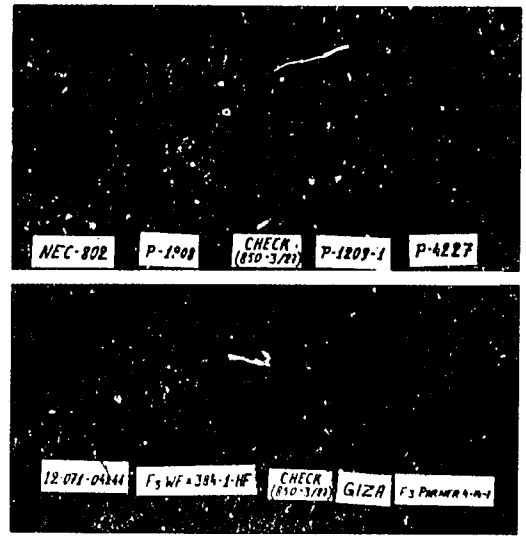
plasm to find parent stocks that can withstand waterlogging and soil salinity and also lines which could be sown on land currently untilled because of its low moisture level.

Breeding for Long, Medium, and Short Duration

The number of days it takes a crop to progress from sowing to seed maturity can be of great importance to the farmer. If the duration is too long, he may find the grain maturing during heavy rains and becoming moldy before it can be threshed and stored; if the crop's duration is too short, he is probably losing valuable growing days. He may, however, need a short-duration crop to plant after he has harvested another in a sequential planting arrangement, or a crop which will not mature at the height of his busiest harvest period.

Short-duration pigeonpea is a successful rotational crop in northern India that provides the farmer with several bonuses in addition to fitting conveniently into his wheat-growing season. The pigeonpea is food for his laborers, the dry stalks provide fuel, and nitrogen residues from the crop may increase soil fertility for the crop that follows. Working with the staff of the cooperative research station at Haryana Agricultural University at Hissar, we have developed and are testing lines of earlier-maturing and much higher-yielding pigeonpea that are particularly adapted to this cycle.

Upper Volta farmers need sorghums with a range of durations to suit different rainfall conditions. The onset of the rainy season can be incredibly variable—from 15 April to 30 July. The farmer always sows when the first good rains come, but, if they are not dependable, he may have to replant—and for this a medium- or short-duration line may be necessary. Thus, long-duration (140 days) sorghum is suitable for planting in April; a medium-duration variety (120 days) for mid-June when rainfall has been delayed; and a short-duration variety for July planting.



Chickpea roots showing high nodulation (above) and low nodulation (below) in cultivars selected from a field screening trial at ICRISAT. Roots in the center are a check. Plants with high nodulation help "fix" nitrogen from the air into plant protein and result in healthier crops.

Breeding for Increased Nitrogen Fixation

The mandate legumes—chickpea, pigeonpea, groundnut—are capable of providing at least some of their own nitrogen requirement by "fixing" the nitrogen from the air into protein in the plant. Fixation is achieved in a symbiotic relationship with the root nodule-forming bacterium *Rhizobium*. Even with low nitrogen levels in the soil, large green plants result.

Higher soil nitrogen levels can be used at the expense of fixation, but the legume plant

is almost always partially self-sufficient in nitrogen. We have shown that there is a wide range of nitrogen-fixing ability and we are selecting superior lines. However, unless the evaluation is made under conditions of very low nitrogen, where visual nitrogen deficiency symptoms occur with poor nodulation, selection must be made by examination of the root system.

In chickpea we can examine nodules and salvage the selected plants to produce seed in the glasshouse, even if the plants were originally grown in the field. With pigeonpea, salvaging of plants is only possible when they are grown in confined containers. This restricts the amount of selection possible, but we have identified superior lines for inclusion in the breeding program.

Most progress in selection has been made in groundnut. A particular variety x *Rhizobium* strain combination (Robut 33 x NC 92) consistently outyields all other combinations tested in a range of field situations in southern India.

With cereals, there is no structural change in the root, although the bacteria fixing the nitrogen are closely associated with it. We have ample evidence that lines of both pearl millet and sorghum vary in their ability to stimulate the fixation of nitrogen by associated free-living bacteria. The maximum quantities of nitrogen fixed are lower than with legumes, but are likely to contribute a significant proportion of the cereals' requirements, especially in the poor soils of the SAT.

We have developed methods for measuring nitrogenase activity associated with the roots of the cereal plants grown in test tubes, pots, and in the field and have selected greenhouse-grown plants that can be crossed or selfed and then grown to produce seed. Selection of superior germplasm cannot be made easily and the choices are limited, but we have identified superior lines for incorporation into breeding programs.

Tests of tô made from ICRISAT's E 35-1 sorghum showed that the keeping quality of the product varied because of differences in preparation in Upper Volta and Mali.

Breeding for Improved Food and Processing Qualities

ICRISAT's two cereal crops, sorghum and pearl millet, are the staple food for millions of people in the SAT. Our scientists try to incorporate adequate nutritional qualities into the varieties they develop, but they also want to produce a grain people will like. Our analyses, therefore, must also consider how the product is to be used, how it will be ground, cooked, and stored.

In Upper Volta, for example, tô made from sorghum flour, cooked in acidified water, and served with a sauce of tomatoes, okra, chil-

lies, cowpea leaves or other ingredients, is the heart of the diet. We studied each step in the preparation of this paste so that we could guide scientists to develop lines that would meet consumers' demands for firmness, flavor, and storage ability.

Keeping quality is particularly important, since tô prepared one day may be kept overnight and used the following morning. We discovered with the tô made from cultivar E 35-1, which was popular in Upper Volta because of its good flavor, did not keep well in Mali because of ash added to the water in the preparation there, and was considered quite unacceptable because of its mushy consistency.

Pulses provide an important part of the protein in the diet of the SAT. To find superior lines, we analyzed a large germplasm collection of chickpea and pigeonpea. Protein content varied widely, from 13 to 26%, with the mean around 20%. Wild relatives of the two plants, however, showed much higher levels of protein content, around 28 to 30% for pigeonpea and 25 to 31% for chickpea, and these are being considered as parent stock for protein-rich lines that are especially important in areas where many people are vegetarians.

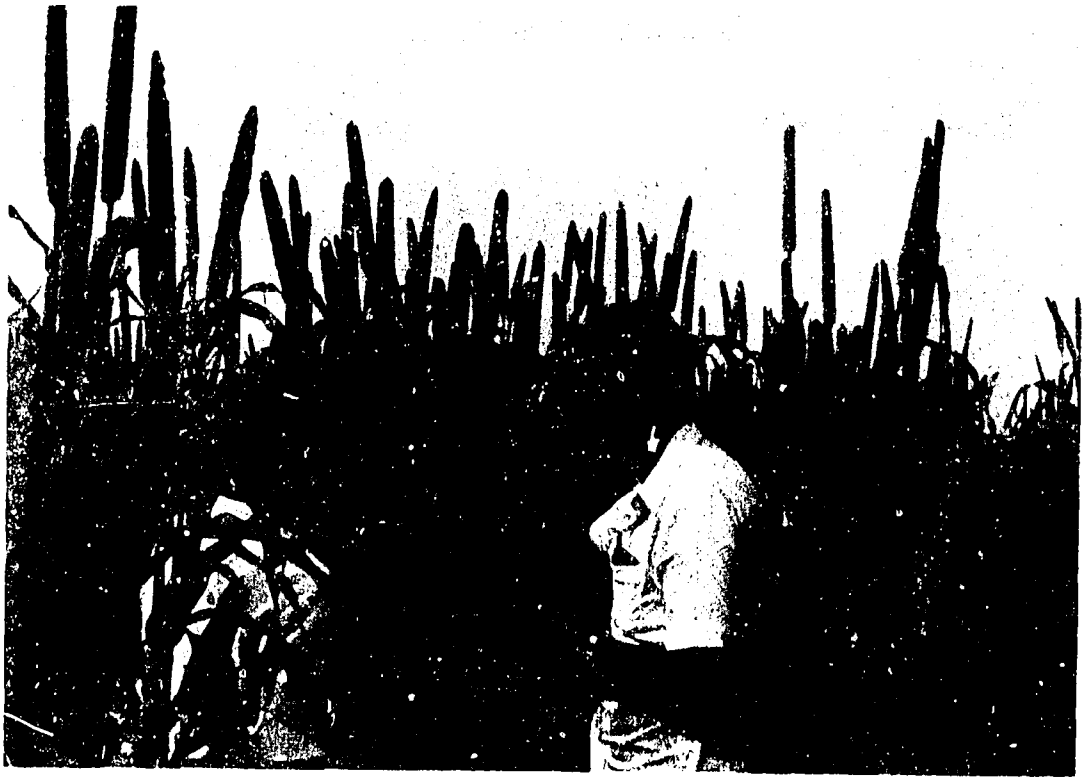
Hybrids and Varieties for National Programs

All of our crop improvement work has a single goal—larger yields of a more stable product. Plants resistant to diseases, pests, and the stresses of the natural environment give more grains for food and seed and hold up well in storage. ICRISAT cultivars are increasingly going to farmers for sowing, and others are progressing through the rigorous process of national testing before being released. We also know that because we make breeding material freely available, ICRISAT-developed lines have been used to create stronger stock in many countries, though the end product may not necessarily bear our imprint. For example, Indian national program pearl millet breeders are invited to select materials from ICRISAT breeding lines each year. In 1980 and 1981 we provided about 2300 samples for them.

Released for distribution. In crops such as sorghum and maize, hybrids have had a marked performance superiority over varieties; for some 15 years since the introduction of hybrids, this was taken for granted in pearl millet also. ICRISAT scientists, however, working through population improvement, have now succeeded in producing pearl millet varieties that give grain yields very nearly as good as existing commercial hybrids but superior in other respects, particularly in disease resistance and fodder production. The cost and difficulty of variety seed production is a fraction of that of hybrids.

The first of these varieties, WC-C75 (of Nigerian derivation), was released nationally for cultivation in India in March 1982 after it had given on average 98% of the grain yield of BJ 104, the costly and currently most widely grown pearl millet hybrid, and 20% more fodder in 140 trials spread over 5 years of intensive country-wide testing. Our WC-C75 is highly resistant to downy mildew and offers the farmer a cheap, resistant product he can count on.

In Sudan, the Variety Release Committee approved use of an ICRISAT-introduced pearl millet selection in 1981 for general cultivation. They renamed it "Ugandi" because it came originally from a Uganda variety. Testing between 1977 and 1979 identified it as a high-yielding and adaptable cultivar that outperformed two widely grown local pearl millets by 13 and 26% under rainfed conditions, by 113 and 115% when irrigated.



ICRISAT's WC-C75 pearl millet has been released to farmers in India; it is a dependable cultivar, resistant to downy mildew, and its stalks are useful as fodder.

An ICRISAT-bred sorghum variety, Diallel Pop 7-862, was distributed internationally in 1979 and has been released to farmers in the lowlands of Ethiopia. The long-headed variety with large white seeds, renamed Melkamash 79 by the government of Ethiopia, has been outperforming all other sorghums in the area. In earlier trials it gave a mean grain yield of 2760 kg/ha, compared with 2290 and 2150 kg/ha from improved local varieties Kobomash 76 and Gambelia 1107.

In national trials. Procedures for releasing seed to farmers vary. Before ICRISAT varieties go into trials, they are extensively tested by our own scientists. After that, they may go through a procedure similar to that used in India: Preliminary trials, followed by Advanced variety trials, and finally Minikit tests at different locations, where small kits of seed are used experimentally for sowing in farmers' fields. If, after 2 years of use in the Minikit, the variety still shows superior qualities, it is likely to be released. Figure 2a, page 8, gives a graphic presentation of this routine.

We hope to have our first sorghum release in India in 1983 or 1984. ICRISAT's SPV 351 was entered in the Minikit trials in 1982, and we expect to enter another in 1983. In nine Preliminary or Advanced sorghum trials for

varieties or hybrids for the kharif (rainy season) and rabi (dry season), our entries stood at or near the top, with three firsts and three seconds. We expect several of these to advance to the Minikit stage.

Development of E 35-1, the sorghum now being tested on farmers' fields in Upper Volta, and Melkamash, the cultivar released in Ethiopia, is a good example of the linked transfer of technology that ICRISAT can produce. E 35-1 was selected from an Ethiopian strain for inclusion in ICRISAT's international trials. In Upper Volta it was identified as having immediate potential and was included in national on-farm trials. Meanwhile, in Ethiopia, a well-adapted selection from ICRISAT Center was used in developing Melkamash.

An ICRISAT pearl millet synthetic developed by recombining seven inbred lines derived from West African and Indian crosses, ICMS 7703, was entered in Minikits in 1982, having initially begun in the All India Coordinated Millet Improvement Project trials (AICMIP) in 1978. In trials it has given larger yields (an average of more than 1900 kg/ha) and appears to be more resistant to downy mildew than the already released WC-C75. During the period 1976-82, the ICRISAT pearl millet improvement program contributed 12 hybrids and 20 open-pollinated varieties to the AICMIP yield trials.

Despite their dietary importance in the SAT, pulse crops have received relatively little attention from breeders. Thus when ICRISAT identified chickpea and pigeonpea as important crops for its research, much groundwork was necessary to identify breeding material suitable for answering the pressing need for improved cultivars.

ICRISAT has now contributed several chickpea lines for testing by the All-India Coordinated Pulse Improvement Project. One of these, ICCC-4, a medium-duration type, has shown considerable promise in central India. In 3 years of testing, between 1978-79 and 1980-81, ICCC-4 gave especially good performance under rainfed conditions in Madhya Pradesh and Rajasthan.

In pigeonpea our breeders have produced several lines that are in their final prerelease stage of testing in the Indian national program. These include ICPL-1 and -6, high-yielding inbred lines developed from existing adapted cultivars, ICP-87, developed from our hybridization program, ICPL-227, which shows resistance to wilt and tolerance to sterility mosaic disease, and ICPH-2, a hybrid arising from our identification and use of the genetic male sterile MS-4A. Because of its special adaptation in the low hill area of Himachal Pradesh, one of our pigeonpea lines has been released there as the cultivar HPA-92.

Groundnut is a latecomer to the ICRISAT mandate and full-scale research efforts have been going on only for the past 5 years, with the result that our breeding lines are still in early testing stages.

Following All-India initial evaluation tests for Spanish Bunch (early-maturing) and Virginia Bunch (late-maturing) groundnut, ICRISAT lines have been promoted to the advanced stage of evaluation.

Our entry in the Spanish Bunch came first with a yield of 1880 kg/ha, compared with the national check of 1690 kg/ha. Two Virginia Bunch entries also performed extremely well: ICGS 6, with a mean yield of 1810 kg/ha, and ICGS 5, with a mean yield of 1700 kg/ha. For these varieties, the national check stood at 1260 kg/ha.

Up to mid-1982 we had sent high-yield, good-quality, early-maturing rust- and leaf spot-resistant breeding material to 18 African countries. In Ghana, Ah 8254 x MH 2 yielded some 3350 kg/ha, well above local checks, which ranged from 2200 to 2500 kg/ha. More than 4000 lines of breeding material with these same desirable qualities

Groundnut under field testing conditions at ICRISAT Center, Patancheru. We have sent more than 4000 lines of breeding material to 43 countries since the program began in 1976.

have also been supplied to 25 other countries.

Parent stock. Hybrids may be the best hope the poor farmer has for getting a higher-yielding and more stable sorghum crop in the limiting conditions of the SAT. Because hybrids produce a limited amount of useful seed for future planting, the farmer must purchase a new supply each year, which gives him some quality control, though at a higher price. We at ICRISAT have just begun experimental production of our first hybrid sorghum for Sudan.

ICRISAT materials have been used as parent stock in three released sorghum varieties in El Salvador, including the award-winning Centa SS-41 and San Miguel 1. Production of seed for a major test of four varieties is under way in Venezuela. Superior yield qualities have been found in ICRISAT lines tested in Guatemala, Nicaragua, Haiti, and Mexico and midge-resistant lines have been useful in Argentina.

The development of better hybrids depends on finding both new male and female parents. In pearl millet many new male parents have been produced, but the availability of new female (seed) parents has been negligible. We have been able to develop a dwarf seed parent (MS 81A) which is highly resistant to downy mildew. This line

was generally distributed to millet scientists in India in May 1981.

It has two advantages—its dwarf stature, which allows the production of a hybrid of any height (depending on the height of the male parent), and its high level of downy mildew resistance, which carries through to its hybrids. It can also be used in experiments to reveal new seed parents at a rate 4 times higher than was previously possible. It is a key to discovering a wide range of new seed parents, and so removes the bottleneck to finding superior new pearl millet hybrids.

Pigeonpea breeders at ICRISAT have isolated male sterile lines of 13 adapted or disease resistant cultivars. These lines have been distributed to national breeders and are expected to provide a boost to the yield of pigeonpea hybrids.

Farming Systems

The SAT farmer has followed the practice of planting long-season local crops that give adequate vegetative growth in good years, but low grain yield. His soils have been subject to weathering and leaching and have poor water-holding capacity. When it rains, such soils often form a crust and the water runs off, causing erosion; heavier soils become gummy and difficult to work.

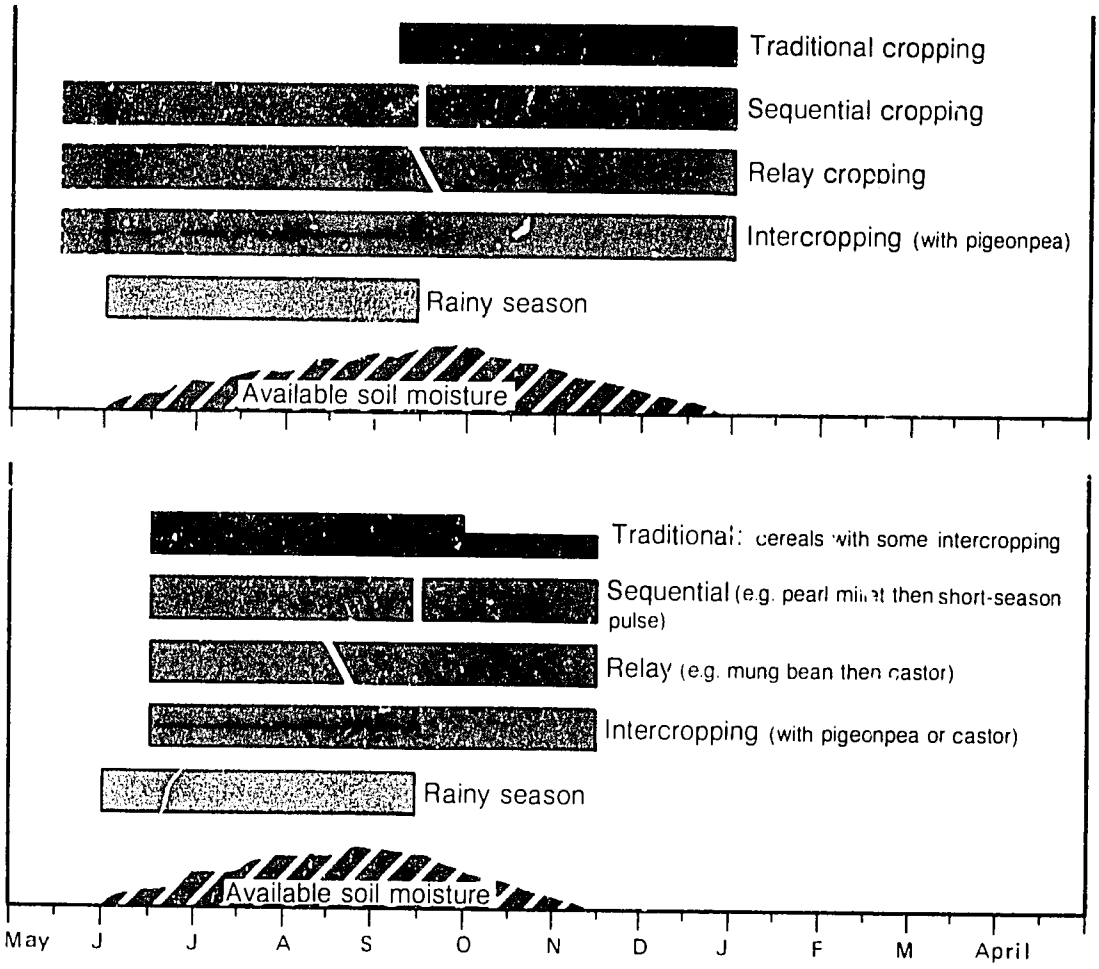
In normal times, this farmer produces enough for himself and his family to get along, and even a small amount for sale at low prices in the market. But with cereal yields of 400 to 500 kg/ha compared with as much as 3000 kg/ha or more in the rest of the world, he is not able to afford improved seed, fertilizer, sprays, or implements. His existence is precarious, especially in those years when his crop fails or produces little because of drought, pests, or diseases.

Increased world food production in the past has been achieved through expansion of the cultivated area. This cannot go on indefinitely. We at ICRISAT feel that we must direct our efforts toward increasing productivity of existing crops and land resources.

A major danger of the short-term increases in cropping intensities of recent years is that they lead to accelerated soil erosion, build-up of pests and diseases, and deterioration of soil fertility if adequate attention is not given to all aspects of agricultural development. ICRISAT's farming systems research aims at developing improved, viable farming methods that will raise and maintain productivity through the best use of natural resources.

Systems for Heavier Soils

Much research has concentrated on increasing the yields of individual crops. But a farmer's overall output also depends on how judiciously he fits his different crops



Improved cropping systems, shown in green, make more effective use of soil moisture than do traditional practices. Systems for heavier soils are shown above, for lighter soils below. Dotted lines in the upper diagram indicate dry seeding before the rainy season begins, an ICRISAT-developed system.

together in time and space. In our research the objective is to develop combinations, or "systems," of crops that make the most efficient use of the full growing period.

The deep black clays in the higher rainfall areas of semi-arid India typify a situation with a long potential growing period: the rainy season itself is about 90 to 100 days and, after the rains, the large store of soil moisture can support growth for a further 90 to 100 days. Traditionally the farmer has utilized only the postrainy period because, during the rains, drainage is poor and the soil is extremely sticky and difficult to manage.

The improved drainage and planting methods provided by ICRISAT in broadbed-and-furrow technology facilitate cropping during the whole 180 to 200 days, and we have developed several improved cropping systems. In simple sequential systems,

improved early cultivars of maize, sorghum, or mung bean have been grown during the rainy season and followed by the traditional postrainy-season crops of chickpea, safflower, or sorghum.

Where earlier sowing of the second crop is desirable, the emphasis has been on relay systems in which the second crop is sown 2 to 3 weeks before harvest of the first crop. Relay systems can present operational problems because it is necessary to sow the second crop between the standing rows of the first crop.

Perhaps the most promising system of all for the deep black soils has proved to be a cereal/pigeonpea intercrop. During the rainy season the cereal (either maize or sorghum) produces only 5 to 10% less yield than a sole crop and, after cereal harvest, the pigeonpea is already well established to produce a postrainy-season crop. On-farm research suggests that this is particularly stable and attractive in practice because it avoids the problems of having to establish the second crop when the upper soil layers may be dry and when workers are busy harvesting rainy-season crops.

Systems for Lighter Soils

On lighter soils the reduced moisture storage capacity curtails the growing period and

Sowing a cereal/castor intercrop on light soils in semi-arid India, following ICRISAT recommendations.

increases the risk of drought. At our Patancheru Center, for example, the growing period on the red soils ranges from about 110 to 150 days, depending on soil depth. This places greater emphasis on the more drought-resistant crops and limits the types of feasible cropping systems. With some improved early-maturing crops, sequential or relay systems are possible and can produce more income than a single crop.

Intercropping systems have proved to be the best means of utilizing lighter soils. Combining early-maturing cereals or legumes with later-maturing and deep-rooted pigeonpea or castor has ensured efficient use of both the rainy period and any residual soil moisture. In the cereal/pigeonpea systems, the cereals have consistently produced 85 to 95% and pigeonpea 50 to 60% of their sole-crop yields; groundnut/pigeonpea has produced 80 to 85% yield of each crop.

Advantages of Intercropping

Intercropping has given such encouraging results on all types of soil that we have turned our attention to improving traditional systems. As an example, sorghum/pigeonpea is one of the most important intercropping systems in India. Sorghum is the more important crop and the farmer tries to maintain its yield by sowing it in high proportions with occasional plants, or rows, of pigeonpea. Yields probably average about 400 to 500 kg/ha of sorghum and 50-100 kg/ha of pigeonpea. Our improved system of sorghum/pigeonpea uses a short, early-maturing sorghum, which, at high population and with fertilizer application, can produce 3000 to 4000 kg/ha. This sorghum crop is still less competitive than the traditional tall, late-maturing local types.

The pigeonpea crop, again with higher populations and better spatial arrangement, therefore, can produce higher yields—500 to 1000 kg/ha, depending on soil type and the amount of residual soil moisture.

Traditional intercropping has some features that make it especially attractive to the farmer in the SAT. Our studies show that the relative yield advantages of intercropping compared with sole cropping can be considerably greater when moisture and/or nutrients are limiting. Some cereal/legume combinations producing about 20 to 30% advantage under well-watered, fertile conditions have given advantages over 3 years of more than 100% under stress situations.

Legume intercrops may make an important nitrogen contribution to the soil under low fertility conditions. In a system of maize/groundnut followed by sorghum, where neither cereal received any nitrogen, the groundnut intercrop provided the equivalent of 20 kg/ha of fertilizer nitrogen for the sorghum.

We have also found that some intercropping combinations provide useful disease control. A sorghum intercrop has produced appreciable decreases in the soil-borne wilt disease of pigeonpea and it appears that a millet intercrop can reduce levels of rust in groundnut.

These are worthwhile findings for the farmer too poor to buy improved, disease-resistant cultivars, fertilizer or costly sprays. Even more important is evidence that intercropping may provide notable yield stability over different seasons. Taking sorghum/pigeonpea as an example, a summary of over 100 experiments showed that if crop "failure" were taken as a monetary return below Rs. 1000 per ha, then sole pigeonpea would fail 1 year in 5, and sole sorghum 1 year in 8. But a sorghum/pigeonpea intercrop would fail only 1 year in 36, an example illustrating that intercropping gives the farmer a high level of insurance against calamitous loss.

Rewards from Research and Collaboration

Anticipated Gains

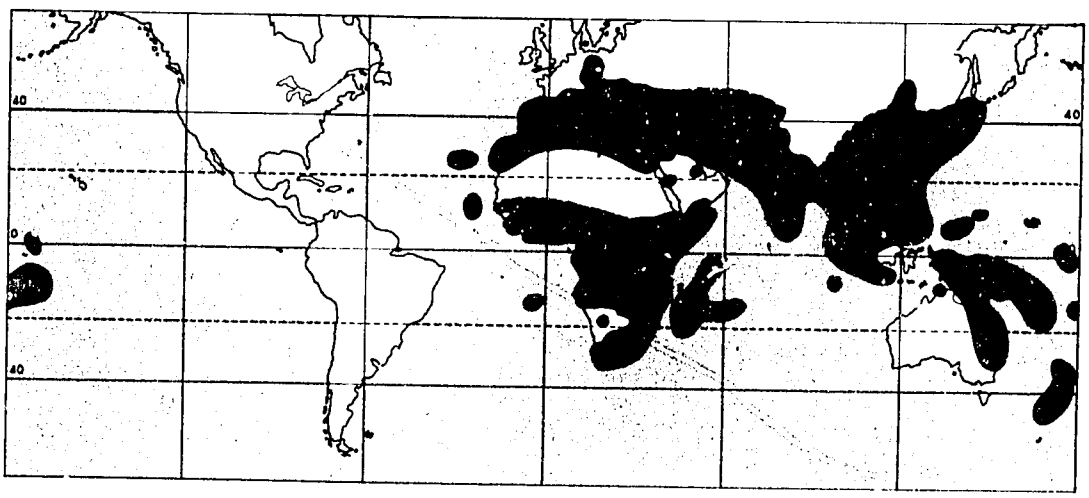
Economic rewards of research are almost impossible to measure exactly. It is possible, however, to give a few examples of ways our research is bringing, or may eventually bring, higher incomes and a better life to farmers in the SAT and boost their countries' GNP by increasing crop yields.

Our examples come from the two main thrusts of ICRISAT's work: crop improvement and farming systems. The examples are based on verifiable Indian data. By applying them to the SAT as a whole, inferences may be drawn that the financial returns to farmers and national economies from our research can be impressive.

As already mentioned, two major achievements of our pearl millet improvement program have been in breeding varieties with very high levels of resistance to downy mildew and effective levels of resistance to ergot disease. Normal yields of pearl millet may be expected to increase by at least 15% because of these resistances. In addition, these improved varieties give 20% more fodder after harvest; and because they are varieties, not hybrids, the farmer can also produce his own seed at a cost well below the most popular Indian hybrid.

These two varieties are WC-C75 and ICMS 7703. If, as seems likely, WC-C75 achieves sufficient popularity to replace lower-yielding varieties on 25% of India's 12 million hectares of land now sown to pearl millet, 15% more yield (about 70 kg/ha) would produce about 200,000 additional tonnes. At 1982 prices this would represent an overall gain of at least US $20 million per year and farmers would also get increased income from extra fodder.

Our surveys have calculated that losses to pigeonpea and chickpea in India from the pest *Heliothis armigera* run to more than



Vast areas, shown on the map above, are subject to crop damage from the pod borer, Heliothis armigera. *ICRISAT's work on control of this pest, carried on in cooperation with world scientists, could lead to savings of millions of dollars annually.*

$300 million a year. Damage to other legumes, cotton, and cereals adds substantially to that figure. Development of resistant plant strains or control by other methods we are working on are expected to lead to a major increase in farmers' income throughout the entire SAT, where this pod borer is a menace to crop production.

Losses in India from sterility mosaic in pigeonpea are about 205,000 tonnes per year and from wilt about 97,000 tonnes (1977-78 data). In East Africa about 14,000 tonnes are lost from wilt alone. If the effects of these two diseases can be halved by the resistant varieties we are perfecting, pigeonpea production could rise by about 8%. At a price of Rs.3300 per tonne, the resulting gain would be about US $55 million per year in India, and a substantial amount in East Africa.

Leaf spot and rust in groundnut during the rainy season are worldwide problems, probably reducing yields by about one-half. If resistant varieties we are testing that lead to a 25% increase in yield were planted over 20% of the Indian area cultivated during the rainy season, we estimate that production would increase from 4.81 million to 5.05 million tonnes. At a price of Rs.2000 per tonne, this could mean a possible gain of $US 53.3 million per year.

Buyers will purchase slightly moldy sorghum if the price is discounted, but such discounts cut the farmer's income in the marketplace. Our scientists are developing sorghum strains increasingly resistant to mold. If these are adopted and mold level can be reduced from 36% to about 20%, our market analysts say consumers are willing to pay 3.4% more. That would mean a gain to the Indian economy of more than Rs.34 per tonne and would boost national agricultural income by US $45 million, since 12 million tonnes of sorghum are grown each year.

Cultivating deep black soils of India during the rainy season, as described in the Taddanpally village case study below, could add a substantial amount to the income of both individual farmers and the nation. Our studies show that from 5 to 12 million hectares of this land, which has traditionally lain fallow during the rains, are suitable for this cropping technology.

Data from the first year's experience at Taddanpally show that the farmer's profits from the new farming system increased his annual income by an estimated Rs.1434 (more than $159) per hectare. The adoption of this technology will require considerable effort in building up support services (extension, credit, inputs). Consequently, even though the system is self-accelerating, adoption cannot be expected to be very rapid in the initial period. Nevertheless, if 5 million hectares were brought into the system, Indian national income could increase by almost $800 million annually.

Not only will individual profit increase substantially, but other sectors of the economy will also gain—the merchants from whom the farmers buy seed and fertilizer, for example, and the landless laborers who gain income weeding and threshing for an additional season.

What will rural people do with such an increase? There is little research on the subject. The evidence we have suggests they would consume more food: more calories from more protein, more sugar and more fat; more health-protective foods such as milk, vegetables, and fruits.

If their incomes increased enough, they might buy more radios, thereby increasing their access to technological information, and bicyles to get to markets. They might even be able to keep their children in school for an additional year or improve their homes and household sanitation.

But how will rural people in the SAT actually profit from ICRISAT's work? What really happens in a farm situation when we try to help India carry our innovations to the small farmer? Can we lead him into the future with the methods and materials within his reach today, with bullock power and modestly priced inputs and minimal risks?

All sectors of the economy benefit when farmers' yields increase through use of improved cultivars and planned farming systems such as ICRISAT is developing. In this busy market, groundnut is in the foreground, pigeonpea is the red produce, sorghum is in the background.

Taddanpally Village: A Case Study of Increased Yields on Deep Black Soils

To find out how our technologies would work for farmers in extensive areas in India, we turned to a 15-hectare watershed at Taddanpally, 40 km north of the Institute, where the farmers were using traditional production methods. We worked closely with the Indian Council of Agricultural Research, Andhra Pradesh Agricultural University, the State Department of Agriculture, and above all, the 14 farmers who collaborated with us.

Components of ICRISAT's recommended technology are six interrelated options, all of them aimed at the national goals of increasing food production, emphasizing rainfed agriculture, and increasing employment. They are:

1. Cultivating the soils immediately after the preceding rainy season when the soil contains some moisture and is not too hard.

2. Improving drainage.

3. Dry seeding of crops before the rainy season begins.

4. Using high-yielding seeds and moderate amounts of fertilizer.

5. Improving placement of seeds and crops for better crop stands.

6. Paying some attention to crop protection, particularly for legumes.

Our socioeconomic studies of results from research at ICRISAT Center over a number of years had indicated that the benefits to a farmer could be substantial; for an expenditure of about Rs. 1200 or US $ 133/ha over his usual amount for materials, labor, and implements, he could earn an additional annual profit of roughly Rs. 3100 or $ 345/ha with the improved system. In similar villages in India's SAT average annual household incomes range from Rs. 2500 to Rs. 3850 ($ 278-428).

The improved technology would call for major changes in the farmer's way of doing things; he would need more labor at different times of the year, more bullock power, and credit to build drains and rent tool carriers. Existing marketing and storage arrangements would probably be inadequate. Taddanpally was chosen because it had the right deep soils, slopes, and rainfall (reasonably reliable and greater than 750 mm per year). After some initial hesitation, the farmers agreed to cooperate in the project.

Though they are very poor, they agreed to pay nearly all of the cost and do virtually all the work needed to test ICRISAT's technology. Where they needed financial aid, the State Department of Agriculture helped them find it through banks or government channels.

Farmers made their own choices on such matters as which crops to plant. ICRISAT agreed to pay farmers up to the normal levels of their traditional yields if the experiment failed, thus removing the major risk element of the experiment for the sake of research.

Work started in February 1981 just after the traditional postrainy-season crops had

Building drains to remove excess water and avoid flooding at Taddanpally.

been harvested. ICRISAT and State engineers surveyed the land and planned the watershed layout, leaving existing property boundaries in place. The farmers smoothed the fields, using their own animals and equipment, though our tool carrier was used behind their bullocks for most operations.

Farmers were willing to install drainage ways on their own land but did not want to work together to build community drains to connect the watershed to the existing main drain. However, when they saw that lower parts of some fields were flooded after heavy rains in the early part of the season, they were persuaded to build community drains (with the State Department of Agriculture paying for the labor). Power sprayers and rodent control materials were provided free for the first year.

At harvest time, the most profitable cropping system was the sorghum/pigeonpea intercrop (Rs.3838/ha or US $426/ha) followed by maize-chickpea sequential crop (Rs.3266/ha, or US $363/ha). Yields of hybrid rainy-season sorghum grown as an intercrop in the watershed were about 2 tonnes/ha, and those of intercrop maize were 1.6 tonnes/ha. Sole-crop maize yielded 2.3 tonnes/ha. The traditional postrainy-season sorghum yielded only 0.7 tonnes/ha after fallow.

When our economic analysts calculated the profits to Taddanpally farmers on the basis of 1975-81 prices (in order to eliminate the factor of price extremes in any single year), they estimated that the net returns from improved watershed management amounted to US $311/ha compared with US $126/ha for traditional fields. Based on market prices, farmers in Taddanpally recovered their direct costs and made a substantial profit.

Sorghum/pigeonpea was the most successful intercrop for farmers at Taddanpally when they cooperated with ICRISAT and Indian government agencies to test our new technology for cultivating black soils.

Of course there were some problems. Parasitic weeds infested the young sorghum. Farmers were not used to growing two crops a year, one of them during the rainy season, or obtaining such high yields. Threshing and storage were difficult in what turned out to be a wet year when it was not possible to dry the grain on the head in the field.

Better lending arrangements will be necessary if the two-crop-a-year system is to work well. Farmers must borrow for seeds, fertilizer, and pesticides for the postrainy-season crop. It usually takes them at least 6 weeks after harvesting the rainy-season crop to dry, thresh, winnow, and market the grain. By that time it is too late to plant the postrainy-season crop, but the bank won't make a new loan until the last one is paid off. A single crop loan with two disbursements, one for each season, is one remedy suggested by our economists.

We know that in the village we had many advantages and that conditions, even in deep black soil areas, are not the same everywhere. Without ICRISAT's guarantee of normal financial returns, will farmers still take a chance on adopting new ways, or will they return to their usual cautious planning? Will lending agencies cooperate when the glamor of official attention has faded?

These are the questions we hope to answer as we continue our research in Taddanpally and in other villages in India and West Africa where we are working with farmers to fit technologies to local conditions. As we observe which practices the farmers actually adopt, which they reject, we can improve the focus and effectiveness of our recommendations on improved farming systems.

Taddanpally is only one village, and improved deep black soil technology only one aspect of ICRISAT's research. Increasingly we will be concerned with other problems in other places.

Communicating the Results of Our Research

Agricultural research begins and ends on the farm. As we at ICRISAT's research centers develop cultivars and farming systems appropriate to countries in the semi-arid tropics, how do we communicate the results of our work and transfer our technologies to those who can best help our ultimate client, the farmer?

Making improved germplasm available to national programs and collaborating scientists is the most effective way to communicate the results of ICRISAT research. Breeding lines of mandate crops that have progressed through the crossing stage to the formation of varieties or hybrids, been accepted for national release, and are in the hands of the farmers giving them higher yields, are solid evidence that we are meeting our goals in crop improvement for the SAT.

But meetings, training programs, Center tours, and our publications are also important ways of telling the ICRISAT research story.

International Meetings

Sponsoring meetings of scientists from many countries has proved to be an effective

The International Workshop on Sorghum in the Eighties was one of five major international meetings sponsored by ICRISAT during 1981

way of telling about our research in spite of the time, money, and energy involved. Many collaborating organizations clearly agree and have co-sponsored such meetings, evidence that they, too, value the concept of bringing together members of an "invisible college" to discuss improving agriculture in the SAT. Such meetings are lively forums in which we give and receive information and improve working relationships with colleagues.

Our first workshop, in 1974, concentrated on farming systems and was held before the ICRISAT Center had opened. During the first few years, one such meeting a year was about all ICRISAT could handle. In 1981 we held five international meetings, including a Symposium on Sorghum in the Eighties that gave 245 scientists from 37 countries a chance for exchange of ideas. A smaller workshop considered *Heliothis* management; 55 experts from 11 countries discussed how to control the pod borer.

Other conferences have considered grain legumes, downy mildew and ergot in pearl millet, agroclimatological research, sorghum diseases, soil-borne diseases of legumes, intercropping, socioeconomic constraints, chickpea and pigeonpea improvement, rainfed agriculture, climatic classification, management of deep black soils, groundnut, *Striga*, sorghum grain quality, and the interrelationships of agriculture, nutrition, and food science.

Each year breeders from India and overseas attend the pigeonpea and chickpea breeders' meets at ICRISAT Center and Hissar. These are held when the crops are nearing maturity so that those attending can observe and select breeding material or individual plants which are most suitable for their own programs.

Training

Training professionals from national program staffs strengthens research capabilities in the SAT. ICRISAT provides educational opportunities and season-long practical experience in field research at the

Trainees at ICRISAT learn about dry-season harvesting of chickpea from the principal training officer.

Center facilities. Our training program teaches agriculturalists to work more efficiently in research, training, and extension programs in the rainfed semi-arid tropics.

By developing practical skills and concepts, the program provides for an increasing number of skilled scientific, technical, and service personnel to assist in improving crop production. The training programs link national, regional, and international research and development of the SAT with ICRISAT's scientific expertise, germplasm, resources, and research facilities that are not readily available elsewhere.

Our first in-service trainees arrived in 1974 to study the production of sorghum and pearl millet. By March 1982, 388 persons from 54 countries had completed 6 to 8 months of in-service training in the mandate crops, farming systems, and special disciplines.

The first research scholar, a young man from the Sudan, began his M.Sc. work in 1975 at Andhra Pradesh Agricultural University. Since then, 56 scholars from 17 countries have completed their Masters or Doctoral degree programs with course work in a university and thesis research at Patancheru. Research scholars come from countries within and outside the SAT; we provide funding for about half and international organizations support the rest.

Our first intern joined in 1974 and since then 10 international interns have completed 2-year postdoctoral programs. Six young men and women are interning at Patancheru in 1982.

Training for postdoctoral scientists from countries of the SAT was developed in 1976 and the following year four researchers came from Thailand, Korea, and Sri Lanka. Altogether, 34 research fellows from 13

countries have finished or are completing these largely ICRISAT-guided research training programs.

At the in-service level, the main focus is on training scientists and technicians. In-service trainees from 26 African, 16 Asian, 9 South American, 7 European countries, and 1 each from North America and Australia, have participated in production, improvement, and scientific research programs. We expanded this program when residential facilities were completed at Patancheru in 1979, and in the early 1980s trainees are to be seen regularly in the fields and laboratories at ICRISAT.

Some of these participants have been released from their jobs to take advanced degrees after their return home, so the full benefits of their ICRISAT training cannot be estimated until they have finished degree work. Many others have already begun to serve their countries. In Botswana, for instance, an ex-trainee is now in charge of one of the major experimental stations. Here is what some other former professional trainees are doing:

- Deputy farm manager in charge of the groundnut breeding program at an agricultural experiment station in Burma.
- Scientist in charge of chickpea breeding research activities at an Ethiopian agricultural experiment station.
- Soil science officer in charge of developing a new agricultural station in Mali.
- Two senior researchers at two Malian agricultural research stations, working on sorghum and intercropping programs.
- Officer responsible for collection, evaluation, and maintenance of sorghum germplasm in the Philippines.
- Scientist in charge of sorghum improvement programs in the Thai Department of Agriculture.
- Officer in charge of grain legume work in Malawi.

Research scholars, fellows, and interns have all taken on new responsibilities since returning from our training. One is now a maize breeder in Zambia, another a technical adviser in oilseeds in Ethiopia, and a third is the millet agronomist at ICRISAT's Sahelian Center, Niger.

Interviews with previous trainees revealed that they found being solely responsible for a season's cropping research program, with peer-review of the results afterward, was a challenging experience. They also appreciated the opportunity to discuss problems and strategies with ICRISAT researchers experienced in a number of different environments and with a range of tropical crops.

A recurring theme was that ICRISAT training was a stimulating introduction to new thinking—particularly in the areas of land and water management, intercropping and sequential and relay cropping, and all the new concepts of farming systems research. The former trainees seek continuing contact with our staff to keep up with research news and comment.

What someone has termed ICRISAT's "center-of-excellence" concept offers important training opportunities for us, for national programs, and for individuals. Less formal training for Indian national extension staff has recently been increased to promote the watershed-based technology for black soils. This training is an integral part of our on-farm verification. These contacts are a significant person-to-person channel of technology and information transfer.

Visitors and Information

Welcoming visitors at our Centers in India and Niger and at other collaborative stations with resident ICRISAT staff is also an important way of telling about our research. From modest beginnings before the ICRISAT Center was established, the

Farmers come to the Center at Patancheru to hear about ICRISAT's work at a special Farmers' Day at the height of the growing season.

number of visitors received each year has climbed to more than 9000 in 1981, including about 2500 farmers.

At Patancheru the visitors, whether they come alone or in groups, learn about ICRISAT's objectives, research, and progress through a slide presentation with recorded and spoken commentary in English and Indian languages. Most visitors then tour the laboratories, farm machinery and other workshops, and experimental plots of special interest to them. Concerned scientific staff answer visitors' questions This direct interaction gives us new insights into research priorities.

ICRISAT publications are addressed to both technical and nontechnical audiences. These include detailed annual reports with descriptions of technical work, information and research bulletins, general guides, newsletters, and illustrated Research Highlights. Some of this material for the general public is also available in French, Spanish, and some Indian languages.

Some documents are issued by programs and are available to collaborating scientists to serve as a basis for discussions of new research findings or to inform recipients about initial data. They are a means of communication between ICRISAT scientists and their colleagues, and also offer a means of follow-up after our conferences.

In addition, members of our staff contribute papers to professional journals and ICRISAT research results are widely available in the scientific literature.

The Next Ten Years

L.D. Swindale
Director General

ICRISAT's first 10 years have been a time for building. We started with a vast, empty field at Patancheru, provided for our use by the Government of India, and a challenging mandate for research. Even before we had completed our physical plant we had begun our work to improve the quality of life of the small farmer of limited resources in the semi-arid tropics.

Today that field is filled with vigorous stands of our experimental crops, some deliberately infected with pests and diseases and displaying a most encouraging resistance to these long-term plagues of the small farmer. Where there was nothing we have fine modern buildings and laboratories, an impressive library, conference rooms, and training facilities, a germplasm bank, and a computer. Our talented staff is doing the research we believe will mean higher yields of all five mandate crops. On-farm verification of new farming systems for rainfed agriculture encourages us to believe that it is possible to make better use of the

When crop yields are enhanced from ICRISAT's improved technologies, many farmers gain extra income by selling animal fodder in nearby towns.

Some intercrops provide effective disease control. Pearl millet intercropped with groundnut results in a marked decrease in rust in the groundnut in this ICRISAT field.

natural resources that are the heritage of millions of poor farmers in the hot and often dry lands where they live.

Our operations are thriving in Africa, South and West Asia, and Latin America. Our scientists are known and respected all over the world. We are pleased that an ICRISAT pearl millet cultivar just released for cultivation in India promises the farmer a cheap alternative to hybrid millet and that in lowland Ethiopia a sorghum we developed is in farmers' fields, giving yields well above unimproved local varieties. ICRISAT breeding materials are also being incorporated into superior lines of pulses in West Asia and groundnut in Africa.

New seed varieties and new farming methods take a long time to develop and are only part of our work. We have had to develop techniques as well—reliable procedures for screening for disease resistance and strategies such as the use of new pheromones and the light-trap grid for assessing pest population densities. Scientists in many parts of the world have assisted us; others are adopting these ICRISAT methods in their own work.

But we do not waste time looking backward. We are proud of our past, of course, but it was only a beginning. At 10 we are ready to take off, to make the findings of our first decade much more available to national programs as we continue with the high-quality research that has become an ICRISAT trademark as familiar as our logo.

Our greatest emphasis in the coming years will be to develop regional cooperative programs to improve the effective transfer of our technologies to scientists and farmers all over the SAT.

In India we will continue our close cooperation with the Indian Council of Agricultural Research and the state agricultural universities through participation in the All India network of crop improvement trials and through joint research projects and on-farm trials. We will develop much closer cooperation with other Asian countries in research on grain legumes and groundnut and possibly in farming systems.

We are deeply concerned about declining food production in West Africa where population pressures continue to mount. Our major effort there will be to develop improved high-yielding varieties that will reduce the widening gap between the supply of and the demand for basic food crops. Pearl millet will be top priority, with sorghum and groundnut close behind.

This effort will be served through our Sahelian Center in Niger and cooperative links with national research in the Sahelian countries, where we will stress the close association between crop production and

social and economic conditions. In Eastern and Southern Africa sorghum and millets offer safe alternatives to maize, which has been extended beyond its useful agronomic limits. We believe ICRISAT can develop satisfactory cultivars to meet the need.

The heads of nine Southern African states have asked us to help them increase their ability to grow adequate food supplies and free them from dependence on foreign sources. We will respond to that request very soon, with regional cooperative programs in groundnut, sorghum, pearl millet, and dryland farming. Eastern Africa will be a priority region for pigeonpea and sorghum.

Our cooperative work with ICARDA in Syria will enable us to serve the important chickpea-producing areas of West Asia and the Eastern Mediterranean.

New sorghum cultivars are being released from our research program for Mexico and Central America, which is based at the headquarters of the International Center for Maize and Wheat (CIMMYT). An increase in the use of sorghum for food is projected for this region, benefiting particularly the small farmers on marginal land. This program, together with those of our Center at Patancheru and the U.S. International Sorghum and Millet Improvement project (INTSORMIL),

Trainees in Mexico examining an ICRISAT cultivar tolerant to cold weather that has shown superior qualities for highland farming.

will also assist in the improvement of sorghum for South America.

Predicting is a dangerous business in the world of agricultural research, because sometimes the pests and diseases and weather outwit us, coming up with totally new challenges just when we think we have conquered a major problem. But I would like to make a few, short, hedged suggestions of what the next 10 years may hold for ICRISAT.

There will be an increase in the use of sorghum in many places in the semi-arid tropics. ICRISAT cultivars and advanced breeding lines will be used to spearhead the increase. Many of these cultivars and lines will carry resistance to grain molds, shoot fly, and stem borers.

In pearl millet we will develop hybrids resistant to the human-toxic disease called ergot. Our high-yielding, drought and pest-resistant varieties will be in use in West Africa and India. Some of these cultivars will be able to supply most of the nitrogen needed for healthy growth.

The use of pigeonpea varieties will increase in many countries where they are now solely a subsistence crop. The cultivars in use will be responsive to inputs and management and be resistant to the major diseases of sterility mosaic and wilt.

Short-duration chickpea developed at ICRISAT resistant to several diseases and tolerant to the serious insect pest *Heliothis* will be in use in India and Pakistan. Winter-sown chickpea will be producing much higher yields of this crop in West Asian countries.

In groundnut we will be able to offer high-yielding breeding material resistant to leaf

In Pakistan, Ascochyta *blight has decimated the chickpea crop in the foreground. ICRISAT's more resistant cultivar in the center is flourishing.*

Improved agricultural production, the goal of all ICRISAT research, can lead many men and women in the semi-arid tropics from subsistence farming to greater participation in the commercial market place.

spots and rust and to some insect pests and viruses. We will help reduce the dangerous spread of aflatoxins on groundnut.

We will refine our experience with watershed-based integrated development and we will be deeply involved with national programs and regional institutions responsible for research, training, and extension. Work which was begun on deep black soils in India during the first 10 years will have been extended to lighter and shallower soils in Africa and Asia. We will have developed a significant capacity to produce crops resistant to drought.

The Sahelian Center, now in a rudimentary state of development, will have become a leading African research and training institution.

At 20, we will have conquered some of today's seemingly intractable problems, and I hope we will have enabled many families in the semi-arid tropics to move up from a subsistence level of living. We may expect to face a whole new world of challenges in the future. Our mandate may have changed a bit, maybe with a new crop or new areas, but the world will still be getting good value from an ever-improving, ever-searching ICRISAT.

Historical Highlights

1972 Government of India and Ford Foundation, acting for Consultative Group on International Agricultural Research, sign memorandum of agreement establishing International Crops Research Institute for the Semi-Arid Tropics; Ford provides administrative and financial support for initial year and India offers land for Center at Patancheru, 25 km northwest of Hyderabad; Dr. R.W. Cummings named first Director.

1973 Institute becomes independent agency with Governing Board headed by Dr. C.F. Bentley of Canada; field research begins on first 16 hectares of land at Patancheru while ICRISAT operates from rented quarters in Hyderabad; initial international staff of 15 recruited.

1974 Construction of administrative buildings, laboratories, housing starts; first trainees, all from Nigeria, arrive; first international workshop takes place.

1975 Prime Minister Indira Gandhi unveils cornerstone of Patancheru complex; Upper Volta operation begins; Governing Board approves addition of groundnut as fifth mandate crop; West Africa Cooperative Program for Improvement of Sorghum and Pearl Millet launched in cooperation with United Nations Development Program.

1976 Mali and Nigeria operations begin and Kamboinse, Upper Volta, becomes primary location for West Africa programs; cooperative research stations in four distinct climatic zones of India approved.

1977 Dr. L.D. Swindale succeeds Dr. Cummings as Director. Dr. Swindale, a native of New Zealand, was formerly Associate Director of the Hawaii Agricultural Experiment Station; Plant Quarantine Unit established at ICRISAT Center.

1978 ICRISAT's Board has its first Executive Committee meeting in Ouagadougou, Upper Volta; first quinquennial review by the Technical Advisory Committee of the CGIAR held in Africa and India.

1979 Prime Minister Charan Singh inaugurates ICRISAT Center on completion of Phase I building program; Genetic Resources Unit established; cereals program divided into separate sorghum and millet operations, each with own interdisciplinary team.

1980 Phase II building program for additional laboratories, conference rooms, long-term cold storage facility for genetic resources launched; at request of nine southern African countries, ICRISAT sends exploratory mission to consider setting up new center in Botswana.

1981 Agreement signed with Government of Niger for establishment of new Sahelian Center on 500-hectare plot 35 km south of Niamey.

1982 Agreement signed with the Government of Malawi for establishment of regional groundnut project for Southern Africa; at Tenth Anniversary celebration ICRISAT proudly records the following achievements.

82	Principal Staff, more than 250 scientific and technical staff, and 900 support staff working in 10 countries.
29,600	books, pamphlets and microforms and 680 periodicals available in the Patancheru library.
71,600	samples in germplasm bank.
57	scientific publications issued; 250 journal articles by ICRISAT scientists published; more than 100 conference papers delivered.
630	persons completed or in process of completing training programs.