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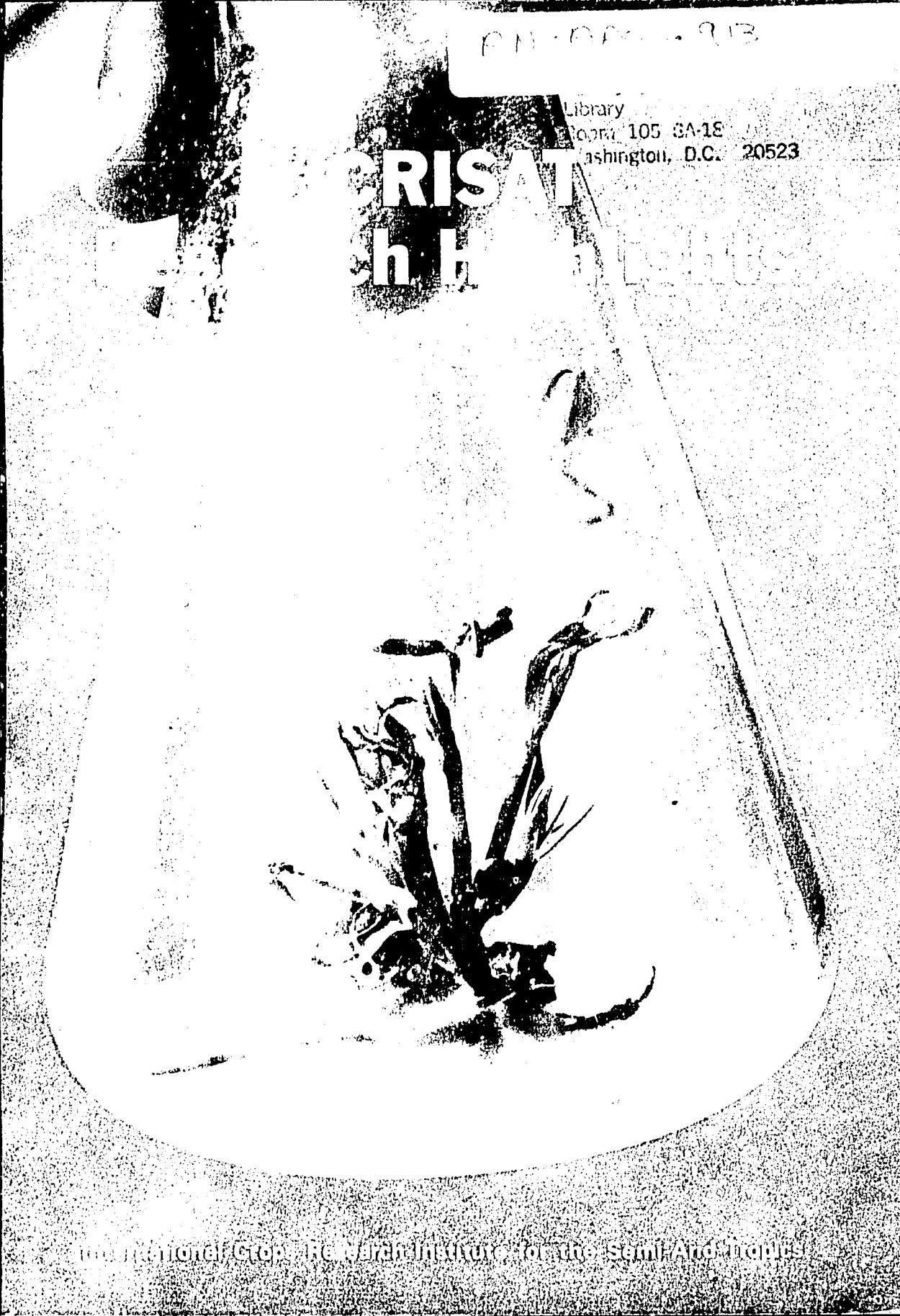

The International Crops Research Institute for the Semi-Arid Tropics

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Cover: Groundnut plant grown through tissue culture techniques, which are being used to produce and multiply new hybrids at ICRISAT (see page 21).

About ICRISAT

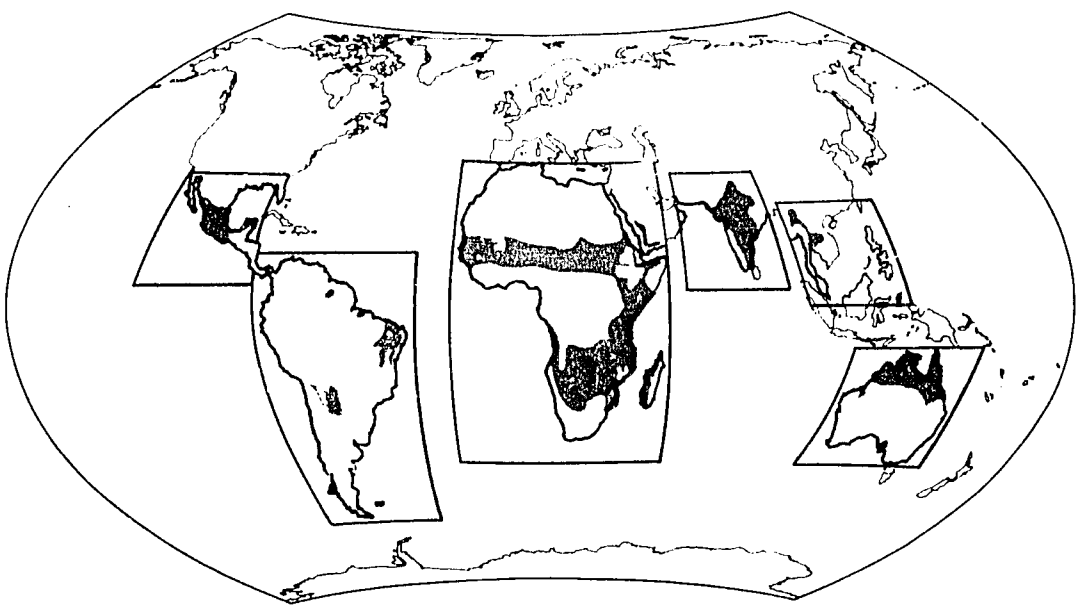
ICRISAT is one of 13 international centers in a worldwide research network devoted to improving food production in less developed countries. ICRISAT's mandate is to improve the yield, stability, and food quality of five crops basic to life in the semi-arid tropics (SAT) and to develop farming systems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

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

The SAT is a harsh region of limited, erratic rainfall and nutrient-poor soils; it is populated by more than 600 million people, most of them living at subsistence levels and dependent for their food upon the limited production of small farms.

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

The SAT produces more than half of the world's sorghum, at least 95% of the pearl millet, 90% of the chickpea, 96% of the pigeonpea, and 67% of the groundnut. But yields of all of these crops are low by developed-country standards and in comparison with their potential yield in the SAT. It is ICRISAT's task to help SAT scientists and farmers achieve that potential.



THE SEMI-ARID TROPICS

Introduction

The tiny groundnut plant in the flask on our cover symbolizes an important aspect of ICRISAT's research: when nature doesn't provide a readily available answer in our efforts to improve food crops of the semi-arid tropics, we try to develop one.

This plant has been grown in our tissue culture laboratory where parts of groundnut plants, their wild relatives, and the hybrids between them are being cloned. These techniques are used to multiply plants with desirable traits, such as disease resistance, so that these traits can be transferred to the cultivated groundnut. The genetic payoff for groundnut growers throughout the world may be several years away from the plant in the flask, but it is developing.

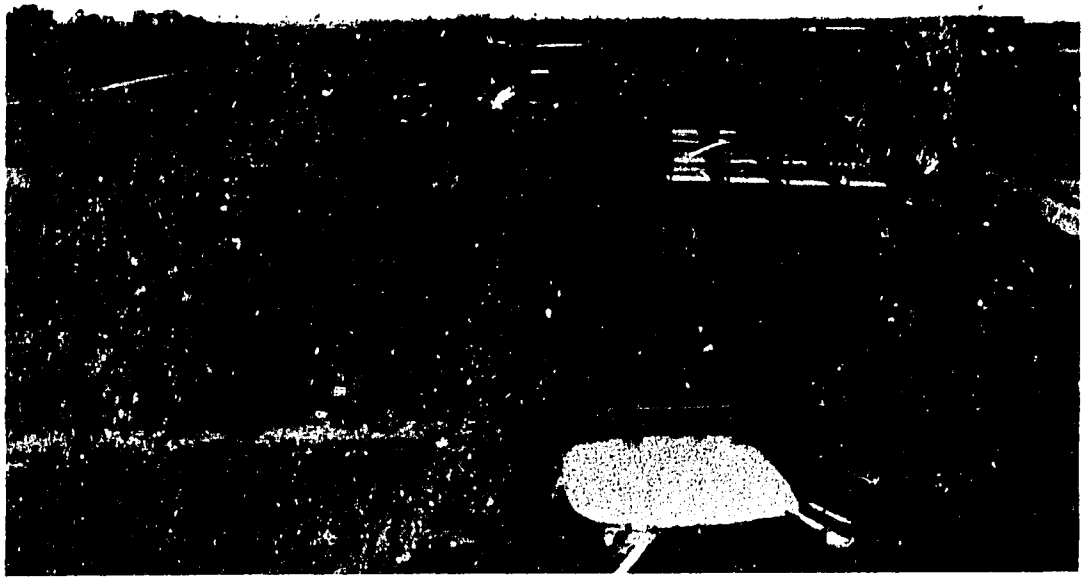
We are as excited at ICRISAT about such research with potential future payoffs as we are about the more tangible or "finished" results that we also report for 1980 and that you will find on the following pages.

ICRISAT is still young as a scientific research institute: we were only 8 years old—on paper—in July 1980, and our crop breeding programs are younger than that. So we are especially pleased to see our first finished products—disease-resistant, high-yielding pearl millet and sorghum cultivars (cultivated varieties)—beginning to reach farmers' fields in India and Africa. In India these new varieties and hybrids have to go through up to 5 years of rigorous testing in government trials against established cultivars before release; in Africa the process is somewhat faster and the transfer to the farmer is more direct, but it still requires years of painstaking work.

Improved technology developed over the past 8 years in our Farming Systems Program at ICRISAT is also beginning to make its way onto farmers' fields in India, and we have started farming systems and socioeconomics research in Africa alongside our more established crop improvement efforts there.

In Syria, working with our sister institute ICARDA, we have developed chickpea lines resistant to *Ascochyta* blight, enabling winter planting and much higher production of this important food crop in the Middle East and Mediterranean area. And in India we have developed early-maturing pigeonpea lines that will significantly increase production of that pulse crop in the north.

These new cultivars have been developed from a valuable world collection of cultivated and wild germplasm that we have assembled at ICRISAT since our Institute's beginning. Not only is this germplasm invaluable to our plant breeders and others to whom we send it throughout the world; we are also preserving for the future many genotypes of plants that would otherwise disappear.



A research field at ICRISAT Center.

The improved cultivars and farming systems technology now beginning to reach SAT farmers are only the first fruits of our research; further advances will be forthcoming and, if we have targeted our priorities correctly, they will also make an impact on farming and food production throughout the semi-arid tropics. The varieties and hybrids being developed at ICRISAT ultimately will produce high yields under rainfed conditions with a minimum of inputs from the resource-poor farmers of this region. Many of these cultivars will have built-in resistance to diseases and pests now limiting yields throughout the SAT and will, in many cases, thrive in nutrient-poor soils by stimulating in their root zones bacteria that transform nitrogen from the atmosphere into a form the plants can use.

Without abundant amounts of fertilizer, water for irrigation, and pesticides, these research achievements will not produce an agricultural "miracle" in the semi-arid tropics. But they will substantially boost food production and are the sort of practical achievements that science can contribute to this region's small farmers of limited means who presently feed most of its people at barely subsistence levels. This report highlights some of the major facets of our work in 1980 toward reaching that goal.

L. D. Swindale
Director General

Cereals

Sorghum and pearl millet are two of the major food crops of the semi-arid tropics and are the fourth and fifth most important cereals in the world. Together they rank first in order of calorie intake in Africa, third in Asia and the Middle East, and are second only to rice in total area planted.

Demand for both of these cereals is increasing in the developing world at a greater rate than their production, and substantial deficits are projected for both by 1990. ICRISAT has an urgent mandate to increase their production.

In 1980 we made substantial progress in moving our new high-yielding and disease-resistant sorghum and pearl millet cultivars closer to the farmers of both India and Africa. The pearl millet cultivar WC-C75 was recommended by the Indian Government for release to farmers after 3 years of All India varietal trials and 2 years of testing on farmers' fields, and another ICRISAT variety,

ICRISAT pearl millet WC-C75 under test in farmer's field in Rajasthan has been recommended for release to Indian farmers after 5 years of rigorous testing in national programs. It is high yielding and resistant to downy mildew.

ICMS-7703, was promoted to the farmers' field stage of testing. Both varieties are resistant to downy mildew, which in past years has caused serious yield losses among Indian pearl millet hybrid crops.

Three other new pearl millet varieties ranked first, third, and fourth in their initial All India trials, and will move into advanced testing in 1981.

Two of our sorghum lines — SPV-422 and SPV-424—ranked first and second out of 20 entries in the 1980 All India postrainy-season trials and will move to the 2nd year of advanced testing next year.

These new cultivars can have a major impact on cereal production in the SAT, where sorghum yields average only 800 kg/ha and pearl millet 535 kg/ha when grown under subsistence farming conditions. Millet cultivar WC-C75 averaged 1830 kg/ha in 4 years of testing and ICMS-7703 averaged 1870 kg/ha for 3 years, in addition to demonstrating their low susceptibility to downy mildew. Sorghum SPV-422 yielded 3860 kg/ha and SPV-424 yielded 3780 kg/ha.

Four of our sorghum hybrids entered the 1st year of All India advanced trials, and two sorghum varieties moved to the 2nd year of advanced trials; one of the latter, SPV-351, was recommended for the 2-year farmers' field prerelease trials.

Similarly, two of our pearl millet hybrids moved forward to the 2nd year and another to the 1st year in the All India advanced trials in 1981.

In Africa our sorghum cultivar Diallel Pop 7-862 yielded 2760 kg/ha across seven locations in 1980 rainy-season trials in Ethiopia, outperforming all other entries; its seed has been multiplied and released to farmers (under the name Malkamash), and it is being used as a standard check against which the performance of other cultivars is compared.

In Kenya our cultivar Ind Syn 387-1 yielded 3470 kg/ha against the local check's 3380 kg/ha, and in India it yielded 3565 kg/ha in the 1980 All India sorghum trial under the designation SPV-394, thus indicating its suitability for cultivation both in India and in parts of Africa.

ICRISAT sorghum SPV-422 ranked first among 20 entries in the 1980 postrainy-season All India trial, yielding 3860 kg/ha.

Drought Screening

The ability of sorghum and pearl millet to withstand long dry periods and survive on limited rainfall is a major reason they are staple cereals of the semi-arid tropics, surpassing wheat, maize, and other cereals in drought resistance. ICRISAT scientists are seeking to improve these capabilities, along with stability of yield, and thus enhance their value to the small farmer of the SAT and the villagers who depend on these crops for their food.

This high-yielding sorghum, SPV-351, has advanced to demonstration trials in farmers' fields in several states of India.

Our physiologists have developed simple and effective methods that screen for drought resistance of large numbers of sorghum lines by evaluating heat and moisture stress effects on germination and subsequent plant development.

One technique used for selection in the advanced growth stage relies on both visual scoring and leaf temperature measured with an infrared thermometer. Stress plots are given a single irrigation at planting; the control plots have two additional irrigations.

The technique at the seedling stage relies on visual scoring alone of three stages—wilting, recovery, and survival percentage. Water is given once following sowing, and not again until severe wilting occurs.

This seedling-stage technique allows early screening of large numbers of breeding lines for promise against drought stress. Other tests are being developed to evaluate the ability of a variety to germinate and emerge through the soil in conditions of temperature and moisture stress and where soil crusting may be a problem.

On the average, sorghum lines with glossy leaves are showing a higher level of resistance to drought at the seedling stage than nonglossy lines.

Glossy lines show multiple resistance to both shoot fly and drought (both have now been confirmed at ICRISAT Center), and from Japan have come indications that they are also resistant to leaf blight (*Helminthosporium turcicum*). An intensive study is under way to understand the

genetics of the glossy trait and how it can best be used in a crop improvement program.

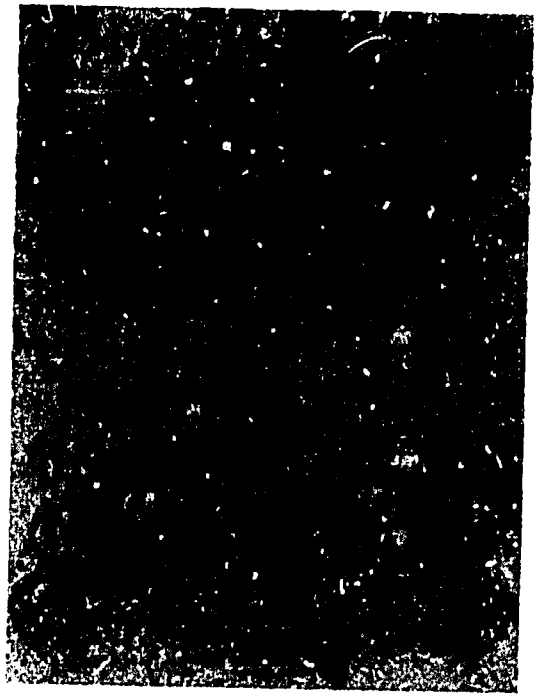
We started a major study in pearl millet in 1980 to determine the effectiveness of direct selection under drought conditions as a means of improving the performance of breeding lines under drought stress. Initially this study is being conducted in the summer-season stress nursery where the onset and duration of stress can be controlled by withholding irrigation. This will permit the testing of selected lines under the same conditions in which they were selected.

Parallel selections from eight different genetic backgrounds are being made in the rainy season (to represent the normal breeding practice) and in both irrigated and stressed summer-season nurseries. Final testing will compare the performance of the products of each selection environment over all three environments. The results will help us to decide how far to go in actually breeding/selecting in stress conditions as distinct from simply testing the products of the regular breeding program for their response to drought stress.

Nitrogen Fixation

Nitrogen is a vital nutrient for plant growth, but SAT soils are generally nitrogen deficient and nitrogen fertilizers costly and difficult to

Screening for heat and drought resistance. Susceptible line D 71-463 at right shows severe leaf firing, while resistant line at left has dark green leaves.



Sorghum lines with glossy leaves, left, generally show greater resistance to drought, as well as shoot fly attack, than do other lines, such as the one at right.

obtain for SAT farmers. Thus development of plants that can use the abundant nitrogen in the atmosphere could have an important impact on SAT agriculture. Our microbiologists are concentrating on three areas of research in their nitrogen studies of sorghum and pearl millet.

1. In a series of nitrogen balance experiments, we attempt to measure all nitrogen inputs and outputs to see where the nitrogen that the plant uses is coming from. This is much easier in the glasshouse than in the field. If plants are grown in pots of soil or vermiculite we know the soil nitrogen input and can measure the amount taken up by the plant; if nitrogen uptake is more than nitrogen depletion in soil, there must be some other input.

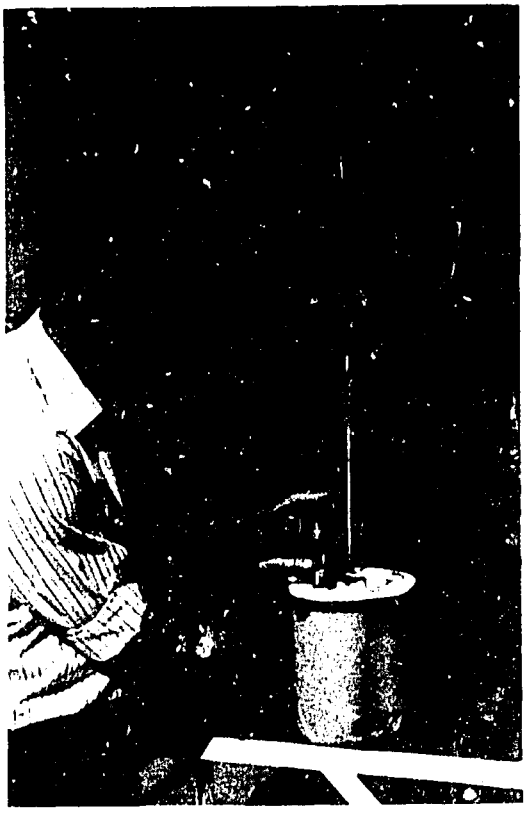
In both field and glasshouse balance experiments with sorghum, pearl millet, and related grasses using soil low in nitrogen or vermiculite with and without added fertilizer, we are finding higher levels of nitrogen uptake and dry matter production than can be achieved from the soil nitrogen content alone. We believe this extra nitrogen is coming from bacteria associated with roots that convert atmospheric nitrogen into a form the plants can use.

2. About 15 kinds of such nitrogen-fixing bacteria have been identified in the soil around sorghum, decreasing to fewer kinds with higher population in the root zone. The root appears to be exercising some positive selection—stimulating certain kinds of bacteria in both sorghum and pearl millet. These nitrogen-fixing bacteria are found even inside the root tissue of these crops. We are interested to see if inoculation of the plant with particular nitrogen-fixing bacteria increases its nitrogen uptake and yield. These studies will continue.

3. Varieties vary in their ability to stimulate atmospheric nitrogen fixation around their root zones. We are screening millet and sorghum germplasm for plants with the greatest ability to do this and to see if this activity can be enhanced by selection and crossing.

Of the 284 pearl millet and 334 sorghum lines tested, about half have stimulated nitrogenase activity. This activity varied with the field, season (rainy or postrainy), and soil moisture content, with most of it occurring in moist soil. Addition of soil nitrate inhibited activity.

Where the soil/root core method of measuring was used in these field studies, there was much plant-to-plant variability, as well as variability between measurements on different occasions. This year we developed a pot culture technique for glasshouse-grown plants that reduces this variability. A tube culture method for screening lines has also been developed. The whole plant is enclosed for complete control of the microorganisms present.



Scientist takes gas sample in new assaying technique developed for nitrogen fixation studies at ICRISAT.

These new techniques of assaying intact plants offer great promise for screening lines and selecting plants with high nitrogen-fixing activity that can then be grown to maturity to produce seed that can be used in crossing programs. Some preliminary crosses have been made between pearl millet lines with high nitrogenase activity.

Research Priorities

We established research priorities for both sorghum and pearl millet in zones of adaptation worldwide to better respond to our international mandate and guide our research efforts through the 1980s.

Our geographical priorities in sorghum for the 1980s were determined to be primarily the Indian subcontinent, West Africa, East Africa, Southern Africa, Central America, and Mexico—roughly the SAT and human food zones as opposed to the non-SAT and animal feed zones.

While the SAT produces sorghum primarily for human consumption, the non-SAT zones (except China) produce it mostly for animal feed. There are noticeable trends of increase in demand for sorghum as direct human food in some areas, particularly in areas of Latin America and East Africa that are marginal for maize production.

In pearl millet we assign our highest geographical priorities in the 1980s to crop improvement in West Africa, northern India, and Pakistan.

In Africa the Sahelian countries of Senegal, Mali, Niger, Chad, and Sudan have a total millet area of over 7 million hectares of the 26 million hectares grown worldwide, and their people depend heavily on the crop as a staple food.

In the Indian subcontinent, Pakistan and the northern Indian states of Gujarat, Haryana, Madhya Pradesh, Punjab, Rajasthan, and Uttar Pradesh have a combined area of 8.4 million hectares under millet and are in greatest need of attention.

In both sorghum and pearl millet, we will emphasize development of high-yielding varieties and hybrids with good grain quality that can withstand drought stress as well as diseases, insect pests, and *Striga*.

Hybrids and Germplasm Utilization

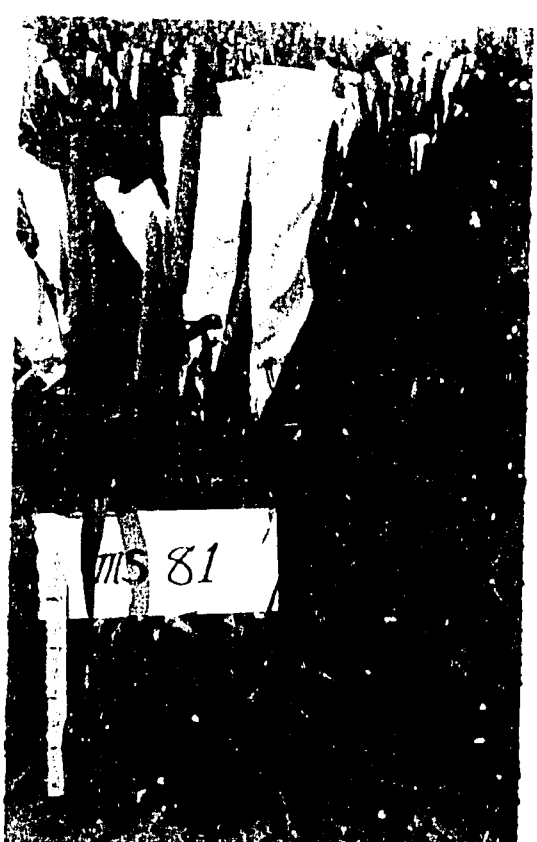
The program to evaluate sorghum hybrids is 3 years old and, as noted earlier, has already produced lines being tested and advanced in the All India trials. Hybrid trials totaling 45 entries were also sent to five other countries this year. A major objective of the sorghum

hybrid program is the development of new seed parents; some 140 entries have been selected and are in various stages of development.

Pearl millet hybrid production in India is limited by the availability of only three male sterile lines, which are necessary to produce hybrids. We have therefore made a special effort to breed male sterile lines, and several of different origins are in the final stages of development. We hope to release the first in 1981

Another thrust in our pearl millet program has been to mobilize new sources of desirable traits, particularly from the primitive (landrace) material of African origin collected and held by ICRISAT's Genetic Resources Unit. In many crops the extraction of useful genetic variability from landraces is a protracted breeding process. We are fortunate that, in pearl miliet, it has proved possible to select many agronomically desirable lines directly from the first crosses between landraces and adapted parents. This new variability, which is being routinely distributed in nurseries mailed to plant breeders, has also provided new male parents to enable us to test a wide range of fully dwarf hybrids.

A special effort has been made to breed male sterile lines of pearl millet, which are necessary to produce hybrids. This line, ms 81, will be released next year



Food Quality (Sorghum)

We initiated a collaborative project with Texas A & M University this year to study the

An ICRISAT breeder selects germplasm from an African farmer's crop. Such germplasm provides new variability in the pearl millet program at ICRISAT Center

African germplasm was used in breeding these pearl millet hybrids at ICRISAT Center.

physiochemical and food-quality properties of sorghum. The project involved 12 cooperators in Africa and America.

An evaluation was made of 25 samples of eight major food types popular across the SAT: chapati in India, tortillas in Mexico, injera in Ethiopia, kisra in Sudan, to in Mali and Upper Volta, bogobe in Botswana, and ugali in Kenya. In each case the aim was to provide data for our sorghum breeders concerning those properties of the grain that merit increased attention in their breeding programs.

From these studies some traits of the endosperm—the stored tissue forming the bulk of the seed—were found to be important criteria by which grains suitable for specific food products may be selected. We believe that an effective international network for the evaluation of food quality was established with this experiment, and the work will continue.

Other Highlights

- We began crossing into hybrid parents resistance to ergot from highly resistant pearl millet lines; this resistance to ergot was also effective in synthetic varieties when all contributing parent lines were themselves resistant.

- In a cooperative project with Reading University, UK, we found that several races of downy mildew may exist; pearl millet

germplasm from West Africa continued to provide high levels of resistance, and lines with stable resistance were distributed and used in our breeding program.

- We identified stable sources of resistance to smut and rust in pearl millet and began using these in our breeding program. A technique that has significantly reduced smut developrnent is pollination of hybrid heads soon after inoculation with the smut pathogen.

- Pearl millet lines capable of performing well under both high and low fertility levels were identified; a newly developed test field was used for this purpose.

- In our continuing efforts to find sources of resistance to shoot fly, we screened 5805 sorghum germplasm lines and selected 323 for further testing. Three of our shoot fly resistant lines included in the All India trials had significantly lower shoot fly attack than the susceptible checks.

A good sorghum crop with high yield, good quality grain, and resistance to grain mold, growing at ICRISAT Center.

Grain mold, right, is a major disease of sorghum. ICRISAT scientists are making good progress in developing lines resistant to this disease; line on left has maintained resistance through 3 years of testing.

- Five sorghum accessions from our germplasm bank and one ICRISAT-developed line with good grain quality maintained their low susceptibility to grain molds for the 3rd year of testing across locations in India and Africa. These lines are good sources of resistance to grain molds for breeding programs.

- We identified eight sorghum lines at ICRISAT Center with multiple resistance to the leaf diseases anthracnose, leaf blight, and rust. Six of these lines were also resistant to four other leaf diseases at several locations in India and Africa.

Pulses

Chickpea and pigeonpea are the principal pulses of subsistence farming systems of the Indian subcontinent and important components of cropping systems in other regions of the semi-arid tropics. The yields of both these crops are low; they continue to be grown on marginal soils with low or no inputs. However, in recent years interest has increased in their cultivation in nontraditional areas and with moderate inputs, and ICRISAT's 1980 research in both crops supports that interest.

Ascochyta Blight Resistance

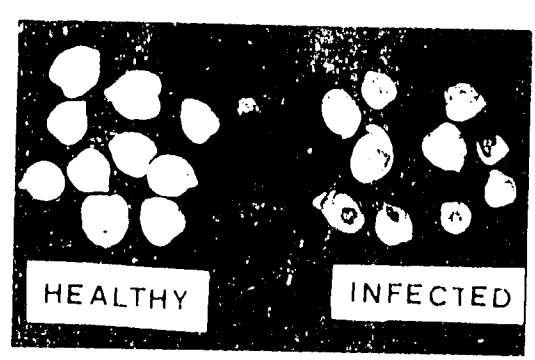
Our joint chickpea breeding program with our sister institute ICARDA, at Aleppo, Syria,

A winter-sown chickpea crop near maturity in the background, in contrast with the traditional spring-sown crop. Ascochyta *blight resistant lines sown in winter have given two to three times the yield of spring-sown Syrian Local*

A chickpea crop damaged by Ascochyta *blight*

was further strengthened this year with the short-term posting of an ICRISAT pathologist and an entomologist at Aleppo. The ICRISAT breeder posted there earlier is supported in his work by ICARDA scientists who also have responsibility for other leguminous crops in ICARDA's mandate. This team has made excellent progress in the 2 years of joint chickpea research at Aleppo, and their work on *Ascochyta* blight resistance is particularly promising.

The principal objective of the joint program is the development of conventional and tall kabuli types of chickpea with resistance to *Ascochyta* blight and with increased seed size and improved cold tolerance for different environmental situations in the Middle East, North Africa, southern Europe, and South and Central America. The kabuli-type chickpea has a large white round grain in contrast to the desi type, which grows in India and has a smaller grain.



Chickpea seeds, right, show effects of Ascochyta *blight damage.*

We have found that if *Ascochyta* blight is controlled by the use of resistant genotypes, winter-sown chickpea produces substantially higher yields than spring-sown crops and allows extension of production into zones drier than traditional chickpea-growing areas.

In 19 on-farm and station trials conducted in collaboration with the Syrian Ministry of Agriculture, our winter-sown ILC-482 produced an average seed yield of 1839 kg/ha, exceeding the yield of spring-sown Syrian Local by 974 kg/ha, or 113%. The superiority of ILC-482 was especially marked at locations where *Ascochyta* blight was so severe that in some cases there was total crop loss of both spring and winter sowings of Syrian Local.

More than 9000 germplasm and breeding lines were screened for *Ascochyta* blight resistance in the 1979/80 crop year. Twenty-one genotypes have now maintained resistance for 2 and 3 years, and an additional 36 progenies and 32 ICRISAT germplasm lines showed resistance this season.

This research promises to have a significant impact on chickpea production, not only in Syria and other Middle East countries, but also in North Africa where it will enable farmers to take advantage of the winter rains.

Early-Maturing Pigeonpea

The most promising area for increased production of pigeonpea in the SAT is in

Large seed size and high yields characterize the new early-maturing pigeonpea lines.

northern India, where in the past the crop has been grown mostly on marginal lands and has had a low priority in relation to wheat, rice, and other cash crops.

We have found that there is a potentially high demand for pigeonpea by wheat farmers if it can be produced early enough in the growing season for rotation with wheat. In some cases, particularly where irrigation costs are a problem, pigeonpea will be substituted for rice as the initial crop.

To be successful in this rotation, pigeonpea must be planted early and mature in less than 150 days, compared with about 180 days required for medium-maturing pigeonpeas.

We have been working on this problem at our Cooperative Research Station at Haryana Agricultural University at Hissar in northern India and have now succeeded in developing very early maturing lines with large seed size and high yield. Two of these, ICPL-81 and ICPL-87, have proven to be earlier maturing or much higher yielding than the best local check, which gave 2080 kg/ha of seed in 123 days in 1980 tests at Hissar. ICPL-81 yielded 2175 kg/ha in 119 days and ICPL-87 yielded 3160 kg/ha in 133 days.

These two lines, along with three other very early maturing selections, will be grown in next year's All India Coordinated Program. In addition, several breeders in northern India will test them in a multilocational trial from ICRISAT.

This work has generated considerable interest among wheat farmers, some of whom are already switching to pigeonpea as a rotational crop. They are attracted by its excellent nitrogen-fixing ability—instead of requiring fertilizer, as does rice, it adds nitrogen to the soil for the benefit of the subsequent wheat crop; it does not require irrigation as does rice, although it will grow better with water; and its stalks can later be used as firewood. The market demand for pigeonpea as a food is strong; it is high in protein and has long been a staple in the Indian diet.

Early-maturing pigeonpea line ICPL-81 yielded 2175 kg/ha in 119 days in trials in northern India.

Disease and Pest Resistance

In both chickpea and pigeonpea we are seeking to incorporate into high-yielding lines resistance to attacks of yield-reducing diseases and pests.

In chickpea we have made crosses between parents resistant to *Fusarium* wilt, *Ascochyta* blight, and chickpea stunt, and resulting populations are being screened to combine resistance to all three diseases in a single plant.

In pigeonpea we are developing multiple-disease-resistant lines through cross-breeding of parents resistant to wilt,

Pigeonpea lines resistant to three major diseases—wilt, sterility mosaic, and Phytophthora *blight—are screened in the multiple-disease nursery at ICRISAT Center.*

sterility mosaic, and *Phytophthora* blight. Three progenies of such a cross have shown good promise and will be evaluated for their yield performance under disease-free conditions at ICRISAT Center.

We also confirmed this year in the wilt-sick plot at ICRISAT Center that pigeonpea has substantially less wilt incidence when intercropped with sorghum than when it is grown alone.

Heliothis, or pod borer, continues to be a destructive pest of both chickpea and pigeonpea. In spite of 5 years' screening, we are still a long way from having selections that are highly resistant to *Heliothis*, but we do have pigeonpea selections that have shown consistently lower susceptibility while producing higher yields in unprotected fields. These are now being used by our breeders and are also being tested at several locations across India by entomologists in the national program.

The chickpea selection ICC-506 has consistently given the highest yield and a relatively low percentage of pod damage in all unprotected tests in which it was entered at ICRISAT Center in the past 3 years. In cooperation with the Max-Planck Institute, Munich, we are further investigating this selection's mechanism for resistance. It has shown an outstanding tolerance to *Heliothis* larval damage early in the season and will be multiplied for more extensive multilocational testing.

Pigeonpea damaged by podfly.

Heliothis *moths* H armigera, *a pod borer, is the major pest of both pigeonpea and chickpea in India. In cooperative work with ICARDA we found all three of these species as pests on chickpeas in Syria.*

Nitrogen Fixation

Pigeonpea and chickpea generally do not require additional nitrogen fertilizer for optimum growth because they are genetically equipped to encourage nitrogen-fixing bacteria to colonize their root system. These rhizobia enter their roots, causing the formation of nodules, where the bacteria transform atmospheric nitrogen for the plants' use.

In the case of pigeonpea we found that a sole crop grown on a black soil field at ICRISAT Center had a large beneficial effect on yields of a subsequent cereal crop, namely maize. Benefits from a previous crop of sole pigeonpea were equivalent to about 40 kg nitrogen/ha applied to the maize crop, which was grown in land kept fallow during the previous rainy season

While chickpea has not demonstrated as great an ability as pigeonpea to fix nitrogen in the ICRISAT Center environment, we have found lines that are consistently superior in both nodule formation and nitrogen-fixing ability. We anticipate including these lines in our breeding programs so that their desirable characters will ultimately be incorporated into more advanced lines.

Medium-tall erect chickpea lines are being developed. The taller plants on the left may have potential for higher yields than conventional types, right

Our studies this year also showed that the nitrogen-fixing activity of chickpea increased greatly with irrigation every 10 days. Nodules continued forming up to 47 days with moisture but ceased forming after 34 days without irrigation. Nodule weight and numbers increased up to 40-fold with irrigation. Yield differences with and without irrigation were equally striking: the test cultivar produced 1.3 tonnes/ha without irrigation and 3.0 tonnes/ha with irrigation. It seems likely that at least part of this improved yield is a result of improved nitrogen fixation.

Developing Pigeonpea Hybrids

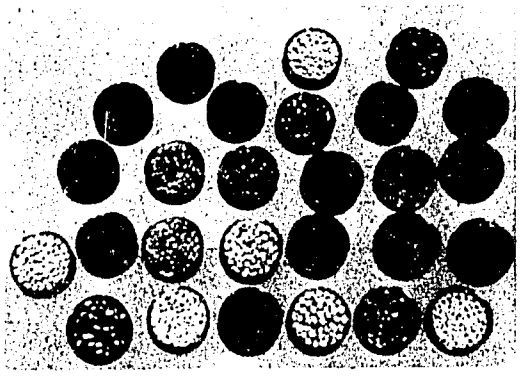
We made good progress this year in our efforts to develop high-yielding pigeonpea hybrids using male sterile lines already in hand at ICRISAT Center, and we identified new sources of male sterility through our cooperative studies at the University of Queensland in Australia.

Since the pigeonpea plant is generally self-fertilizing, male sterility is a key element in breeding hybrids and producing their seed commercially; it eliminates the need for hand emasculation of individual plants that otherwise would be necessary in one line of the parents that are being crossed, to ensure the production of cross-pollinated seed.

The seed of hybrids, unlike that of varieties, cannot be replanted; it must be produced anew each year under controlled cross-pollination in the field. But hybrids generally tend to give higher yields, and our recent studies indicate that the cost of producing hybrid seed commercially will not be a bar to acceptance by farmers if their yield is sufficiently attractive.

We are continually searching for male sterile lines that show high specific combining ability to produce high-yielding hybrids. One of our crosses at ICRISAT Center that has consistently shown good performance is being multiplied this year for multilocation testing in India. In addition, we have produced several new hybrids that will be tested at ICRISAT Center. These now include male sterile lines with an early-maturing background. Several breeders have taken our male sterile lines and are either developing them further or incorporating the male sterility characteristic into locally adapted varieties.

The pigeonpea germplasm collection includes more than 8000 accessions. Its diversity is illustrated by the variation in seed color and size.



Flowers, with petals removed, of normal and male sterile pigeonpea plants. Male steriles, on right, which lack pollen are being used for production of hybrids.

Our knowledge of genetic male sterility was broadened this year by three findings at Queensland, Australia:

1. We identified the male sterile gene for the translucent anther trait in a pigeonpea genotype with a photoinsensitive background. So maturation is not controlled by day length as in photosensitive types. The anther is the pollen-bearing portion of the plant stamen. Unlike regular anthers, translucent anthers do not release pollen, i.e., they are male sterile.

2. We found an entirely new source of genetic male sterility in material selected from the pigeonpea cultivar Royes developed in Australia, and this source is being maintained in ten plant lines of varying times to maturity.

3. A third new form of genetic male sterility was isolated from an early-maturing photoinsensitive line. The anthers are completely devoid of pollen grains and at maturity are brown, shriveled, and arrowhead-shaped, which provides a fast and efficient way to recognize these plants in the field.

All three of these new sources of male sterility will be integrated into the ICRISAT breeding program.

Other Highlights

- We observed differences among chickpea lines in their ability to germinate with limited moisture. This is especially important since chickpea is normally grown in the postrainy season under receding moisture conditions.

- Our research indicated that the protein content of chickpea seed obtained from saline fields is considerably less than from nonsaline soils—15.7% compared with 27.3% in our experiments.

The multiseeded character can contribute to improved yields. Four seeds in one pod are unusual, but some chickpea lines regularly produce two or three seeds per pod.

- We identified several pigeonpea lines with a high degree of tolerance to salinity, which may extend the cultivation of pigeonpea into areas not presently suitable. These will be tested for one more season.

- Our experiments in mechanized pigeonpea harvesting were extended to Fiji through cooperative research with the University of Queensland in Australia. A crop of 40 hectares of the cultivar Royes was harvested and sold to a local dhal manufacturer who reported excellent consumer acceptance. This has renewed interest in the growing of pigeonpea in Fiji.

- We established that irrigating late-sown postrainy-season pigeonpea gave increases up to 75% in seed yield under conditions that exist in peninsular India.

Groundnut

In addition to being an important food crop, groundnut (peanut) is one of the most important cash crops for the small farmers of the semi-arid tropics because of its high oil content. Of the world supply of groundnut, 67% is produced in the SAT despite low yields that average only 800 to 900 kg/ha, compared with 2500 kg/ha in some developed countries.

Our scientists are working to increase groundnut yields by developing plant lines that will better resist the diseases and pests now limiting production in the harsh environments of the SAT. This year they made significant progress in that direction.

Arachis hypogaea, the commercially cultivated groundnut, came originally from South America and has wild relatives there that are resistant to many of the diseases and pests that attack groundnut. ICRISAT scientists, utilizing sources of resistance from both wild and cultivated groundnuts,

Cotton soaked in hormones is applied to base of incompatibly pollinated flower as first step toward producing new hybrids in the laboratory through tissue culture techniques.

Hybrid seed that won't mature on the groundnut plant is cultured and multiplied in tubes in the cytogenetics laboratory.

have achieved considerable success in breeding lines resistant to rust and leaf spot but not thus far to some of the viruses and insect pests. Some wild relatives with resistance to viruses and insects have proved incompatible with *A. hypogaea* and could not be cross-bred because fertilization does not occur, or because pods do not develop after fertilization. But our cytogeneticists have successfully used growth hormones to increase the number of pods produced following fertilization of incompatible parents. The hormones are applied in a wad of cotton gauze wrapped around the ovary immediately after hand pollination.

Although growth hormones have been used for other purposes, this is the first use of this technique in groundnut, and we have provided details to other scientists. To date these growth hormones have not entirely overcome the incompatibility problem because the seeds and pods that develop from this treatment often do not reach maturity. So our scientists excise the immature pods from the plants and bring them to the laboratory, where the seeds are removed and grown using tissue culture techniques.

Tissue culture techniques to grow entire plants from parts of plants have been known for many years; however, they have not been

Peanut clump virus severely stunts plant growth and can cause heavy crop damage, as in this field near Ludhiana, northern India.

very successful with a wide range of *Arachis* tissues until the past year, when our scientists succeeded in growing whole plants from almost all parts of the groundnut plant. Pieces of the plant are dissected out under sterile conditions and put in laboratory flasks on a medium that contains all necessary nutrients and hormones to sustain growth. The composition of the culture medium determines whether the plant piece will produce roots, shoots, or embryoids. Multiple shoots obtained from one piece of plant on one medium can be separated from each other and transferred onto a different medium to induce them to produce roots. These young plants are then transferred to sterile soil under controlled conditions in the laboratory for further growth before planting outside.

From this process, and their earlier work with compatible lines, our scientists hope to develop hybrids that will add substantially to groundnut production throughout the SAT and in other parts of the world.

Peanut Clump Virus

Clump disease has now been recorded in two more states of India since it was found in the Punjab in 1977. This virus causes severely stunted plants with small, dark green leaves, which generally fail to produce pods. Even late infection can cause losses of up to 60%.

The sap-transmissible virus isolated at ICRISAT Center has been further characterized since our report in the 1979 Research Highlights. We have now identified a suitable host on which to maintain the virus for purification and developed a satisfactory purification method. The virus thus obtained has been inoculated or grafted onto healthy groundnut plants where it reproduced the disease. The purified virus contains approximately 5% RNA. The microscopic rod-shaped virus particles (1979 Research Highlights) are 200 to 500 nanometers (nm) long and 23 to 25 nm wide, with a central hollow core.

The virus has an extremely wide host range and also infects several weeds that commonly occur in groundnut fields.

This year, in collaboration with the Oilseeds Breeding Section of Punjab Agricultural University (PAU), Ludhiana, India, we found that several nematocides reduce the incidence and spread of the clump disease, a further indication that nematodes may be transmitters of the virus. Also in collaboration with PAU, we screened nearly 150 groundnut breeding lines in infected soils of the Punjab where the disease has recurred for three consecutive years, showing up to 98% incidence in susceptible cultivars the previous year. Eight lines showed no disease symptoms and ten others showed very low incidence. These lines are being retested under field and laboratory conditions before conclusions are drawn on their possible resistance or tolerance.

The plant in foreground infected with bud necrosis disease will produce no pods; the uninfected ones will produce a full yield.

Bud Necrosis Disease

About 20 years ago only a few insects were regarded as important pests of groundnut. Today, however, insect pests have become a major constraint on groundnut yield, and among the most important both in India and worldwide is the thrips *Frankliniella schultzei*. This thrips is the major carrier of the virus that causes bud necrosis disease of groundnuts in India.

Spread of bud necrosis disease is mainly associated with immigrant thrips, and although migrations of thrips to groundnuts occur throughout the growing season, the large-scale migrations at ICRISAT Center take place in August and January. These insects are carried on the prevailing winds, mainly at dusk.

Early infection can lead to total yield loss; late infections in the pod-filling stage do not greatly reduce yield. The number of thrips is independent of the number of plants per unit area, so higher plant density results in a proportional decrease in the number of thrips per plant and the percentage of infected plants. Some lines are less susceptible than others to field infection by bud necrosis disease. Insecticides are effective only if applied twice a week throughout the season or in three to four sprays during thrips immigration.

Based on these findings we have recommended a combination of cultural and insecticidal methods to reduce damage from the disease. This consists of (1) early sowing (about 6 weeks before mass immigration of thrips), (2) higher plant density, (3) use of less susceptible cultivars, and (4) use of insecticides during thrips immigration. When all these practices are followed, substantial reductions in disease are obtained.

A further method of controlling the disease is by utilizing sources of resistance to the insect. We have recently located such cultivars and they are now being used in breeding programs to combine this desirable trait with high yield. Thrips is among the four insects of worldwide importance selected for ICRISAT screening; the others are jassids, termites, and aphids.

Usually only one flower will bloom in any one day from a single cluster of groundnut buds. We are now developing lines with synchronous flowering (left) that will produce many pegs, or fruit stalks, from a basal node, which will mature at the same time (right).

Groundnut lines susceptible to rust are flanked by rust-resistant lines.

Promising lines have been selected, and some of these have been sent to the USA and Brazil for further testing where other thrips species are important pests.

Other Highlights

- We supplied breeding material from our rust-resistance, high-yield, and earliness projects to breeders in 13 countries and identified several additional rust-resistant lines that performed well in subsequent evaluations for yield potential in field trials.

- Our research showed that cultivars resistant to rust in Hyderabad were also resistant in Africa and Southeast Asia, an important finding for research strategies. Rust is a major cause of yield loss throughout the SAT.

- We observed that the amount of cancer-causing aflatoxin *Aspergillus flavus* can produce in groundnut seeds differed between lines. We are continuing to explore the reasons for this variable tolerance.

- Under nonirrigated unsprayed conditions, 15 selections of our advanced breeding populations outyielded the standard check cultivars and, under irrigated high-input conditions, 40 selections

A healthy groundnut crop at ICRISAT Center. This disease-free crop, grown under irrigation, will yield 6 tonne/ha compared with the average 0.8 tonne/ha in the SAT.

outyielded the checks. Nine selections were common to both situations.

- In ICRISAT field experiments nitrogen fixation in groundnut was adversely affected when it was intercropped with cereals that received fertilizer nitrogen.

- We determined that nodulation in groundnuts is controlled by a pair of independent duplicate genes. This facilitates development of nonnodulating lines that are being used to assess the response of groundnuts to fertilizer nitrogen in the absence of the nitrogen-fixing bacterium *Rhizobium*.

Farming Systems

Plans were made this year to test outside our research station and headquarters in India a farming systems technology that has proved consistently successful for 8 years inside the fence. We accepted an invitation from the Government of Andhra Pradesh to participate in the agricultural development of Medak District, the political subdivision in which ICRISAT Center is located.

The focal village for ICRISAT's work will be Tadthanapalle, 42 kilometers northwest of ICRISAT Center. We will develop with farmers and local agricultural officials in 1981 a small watershed of approximately 15 hectares on which we expect to demonstrate that agricultural production can be markedly increased. The objective will be to grow two crops a year—of the farmers' choosing—on deep black soils (Vertisols) where they are now growing only one. In large areas of India such land is traditionally left fallow during the monsoon and cropped only once, after the rainy season.

ICRISAT's technology, developed and refined in close collaboration with Indian agricultural universities and government research organizations, involves:

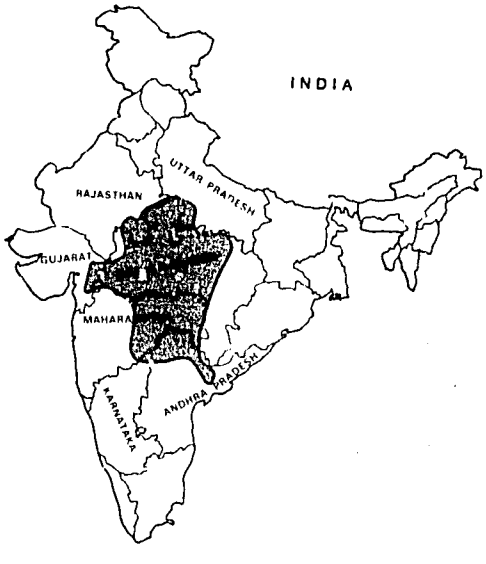
- shaping the land into graded broadbeds and furrows to facilitate cultivation and surface drainage;
- preparing seedbeds during the dry season with improved bullock-drawn equipment;

Farmers and agricultural officials of Medak District, India, learn firsthand at ICRISAT Center about new technology that will be used in farming their deep Vertisols (black soils) in on-farm experiment.

- sowing dry just ahead of the monsoon, before the soil becomes wet and sticky;
- using moderate amounts of fertilizer and recommended high-yielding cultivars;
- cultivating a postrainy-season crop on the same land after the first crop has been harvested.

Farmers and local agricultural officials have been to ICRISAT for familiarization and training in this technology and will implement it in 1981 with our close cooperation. If the technology is as productive for them as it has been within ICRISAT Center, we look forward to its spread to other areas of India and a substantial increase in agricultural production.

Our research to date indicates that this technology works best on deep black soils in areas with dependable annual rainfall, averaging from 750 to 1250 mm per year. Large areas of central India are included in this belt. The technology has not been as productive in areas of less dependable rainfall, or on red soils (Alfisols) or shallow black soils, although even in the latter cases it has been more productive than traditional farming methods. We shall continue to seek improvements in those areas and explore in the years ahead the potential for adaptation and use of this technology on suitable soils in Africa and other areas of the SAT.



Deep black soils in areas of dependable rainfall (shown in color) take in much of central India.

Soil Fertility Studies

Soils in the SAT are generally low in fertility. They will become even more deficient as cropping intensities increase and new cultivars with higher yield potential and nutrient requirements are introduced. Nitrogen and phosphorus, usually the most limiting nutrients, are emphasized in our continuing research on the need for fertilizer. Particular emphasis is given to intercropped cereal/legume mixtures.

Nitrogen

Experiments have now been conducted on black soils over three successive rainy seasons to assess the response of sorghum to nitrogen fertilizer, and to determine whether the density of sorghum plants or introducing a pigeonpea intercrop influenced the response.

Responses to fertilizer nitrogen showed that it was used very efficiently at the rate required by the crop in a particular year, but this rate varied markedly with seasonal rainfall conditions. In 1979, a season with two severe midseason droughts, the maximum increase of 1600 kg in yield of sole sorghum resulted from nitrogen fertilization at 40 kg/ha; but in the average and high rainfall years of 1977 and 1978, the sorghum crop responded to even higher rates of nitrogen, and the maximum responses of 3200 and 3700 kg grain/ha were observed at 80 and 120 kg applied nitrogen/ha.

Dramatic response of sorghum to nitrogen fertilizer in a black soil is seen in crop at right in trials at ICRISAT Center.

Intercropping with pigeonpea generally affected responses of sorghum grain yield to nitrogen only to a small extent. However, yields of the pigeonpea were usually depressed by increased populations of the sorghum intercrop and increased nitrogen fertilization rates to the sorghum. The overall effect was that the biological advantage of intercropping decreased with an increase in the rate of nitrogen fertilizer applied, though there was still a good advantage in intercropping (40%) at high rates of nitrogen application.

Similar experiments were conducted with millet/groundnut intercrops on red soils in the 3 years 1978-80. Increasing the rates of nitrogen fertilizer caused decreases in the advantages of intercropping. Nitrogen fertilization of the cereal in an intercropping system produced less advantage for the millet/groundnut intercrop on red soil than for the sorghum/pigeonpea combination on black soil. The overall biological advantage of millet/groundnut intercropping was therefore much less than with sorghum/pigeonpea intercropping, so there appears to be little advantage in intercropping millet and groundnut if nitrogen fertilizer is used.

Phosphorus

There are very few experiments in SAT India in which the long-term effects of phosphorus

fertilization on dryland crops have been examined. In 1976 we began a long-term experiment to compare the efficiencies of rock phosphate and single superphosphate as sources of phosphorus. Two series of replicated plots were established with a simple 2-year rotation of sole sorghum followed by millet/pigeonpea intercrop.

On this slightly acidic red soil, superphosphate showed clear superiority to rock phosphate during the first 4-year cycle—an increase of more than 100% in the grain production of sorghum and millet. The rock phosphate treatment produced only a small increase in yield.

This experiment will be continued for another 4-year cycle to measure the buildup of phosphorus in the soil, as well as to obtain additional information on the stability of the responses to phosphorus.

In the above experiment pigeonpea responded only a little to applications of phosphorus. In another field experiment pigeonpea gave better responses when the fertilizer was applied 30 cm deep instead of at the customary 5 cm. Additionally, glasshouse experiments showed that the roots of pigeonpea are much more efficient than those of sorghum at absorbing phosphorus from deficient soils. The uptake of fertilizer phosphorus was not improved by regular moistening of the zone of application.

West African Rainfall

We have found in our research that, in order to improve agricultural production in a given area, we must have a thorough understanding of the climatic environments of that area. Studies carried out by agroclimatologists in our Farming Systems program produced the rainfall maps on which we are now planning our future strategy for deep Vertisol (black soil) double cropping in India, mentioned above, and our experiments in other areas of India.

This year our agroclimatologists published a study of rainfall characteristics in West Africa that should prove beneficial for future agricultural research and development there. The study of Senegal, Mali, Upper Volta, Niger, and Chad covered a total area of about 4.2 million square kilometers between 7 and 15°N and 17°W and 24°E. Data on mean monthly rainfall, potential evapotranspiration, and dependable rainfall for over 280 locations were included.

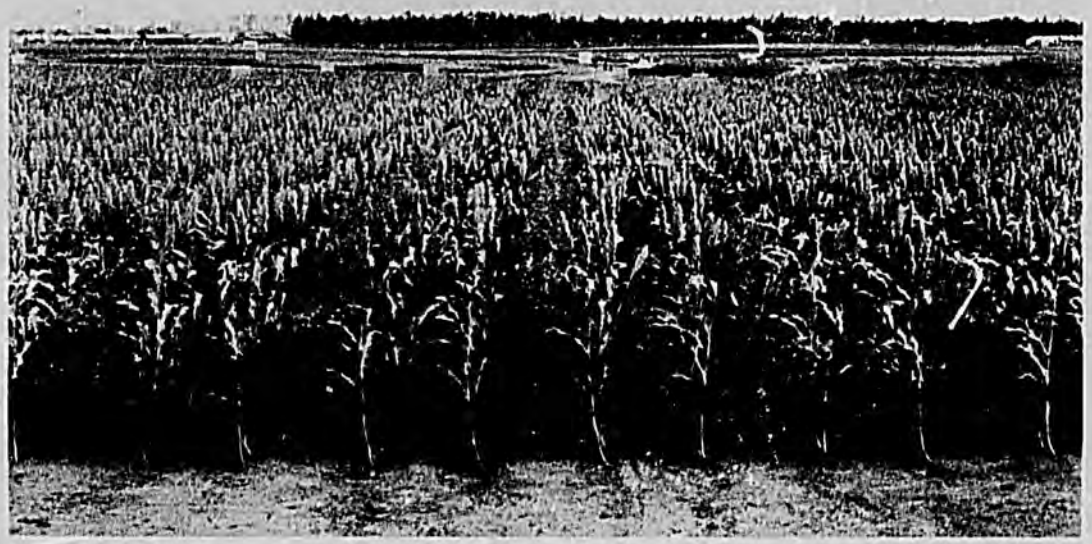
Maps showing mean annual rainfall and mean annual potential evapotranspiration have been prepared for Senegal, Gambia, Mali, Upper Volta, Niger, and Chad. These are based on long-term data not previously published in cartographic form and provide a detailed picture of the distribution and incidence of West African rainfall.

The mean annual potential evapotranspiration over West Africa follows the general pattern of the distribution of rainfall. The values of potential evapotranspiration are low in the higher rainfall areas and increase near the Sahel.

Wheeled Tool Carriers

One of our long-term aims has been to develop an all-purpose animal-drawn wheeled tool carrier for use on small farms of the semi-arid tropics. Most of our efforts in this direction have been directed at testing and adapting a French model, the Tropicultor, which is now being manufactured commercially in India.

In 1979 we began collaboration with the National Institute of Agricultural Engineering (NIAE), U.K., to develop an alternative to the Tropicultor. They are designing and providing the prototypes that we field-test. This year we made significant progress on this model which will offer alternative design features that make it easier for the farmer to operate.



A farmer's traditional sorghum/pigeonpea intercrop (top) will typically produce about 500 to 1000 kg/ha of sorghum and about 200 kg/ha of pigeonpea. An improved sorghum/pigeonpea intercrop such as this one at ICRISAT Center (bottom) can produce more than 3000 kg/ha of sorghum and about 1000 kg/ha of pigeonpea. Intercropping studies play a vital role in our farming systems research.

The NIAE tool carrier, equipped with seed-fertilizer drill, in use at ICRISAT.

The NIAE tool carrier is designed to carry implements for all tillage, seedbed preparation, fertilizer application, planting, and weeding operations on flat, ridge, or bed systems. It is also usable as a cart.

To minimize the cost, we have standardized the track width at 150 cm, which is suitable for many cropping systems and row spacings on flat, ridged, and bed cultivations. A toolbar of 40 x 40 mm square steel section has been adopted in order to standardize it with other tool carriers. This ensures the interchangeability of implements among different machines with a common system of attaching them to the tool carriers.

The working depth of implements is adjusted by using a vertical threaded rod between the axle of each wheel and the frame. In this way the frame and attached implements can be moved up or down in relation to the wheels.

An over-center lifting mechanism locks itself both when the implements are raised and when lowered to the working position. The lifting lever moves through an arc of about 200° to give a 20-cm lift to the toolbar.

To facilitate manufacturing the NIAE tool carrier, most of the components involve simple fabrication limited to cutting, welding, and drilling processes. The threaded rod used for depth adjustment is a standard truck jack screw. In order to minimize the cost, a secondhand car-axle assembly and used tires are fitted.

Other Highlights

- We found in preliminary tillage experiments on red soils, under the broadbed-and-furrow system, that increasing the average depth and thoroughness of tillage from 2.5 to 7.0 cm increased crop yields by 25% and also significantly enhanced water infiltration and the soil nitrogen level.

- Our farm machinery unit designed a new planter costing about half that of existing planters and with improved performance capabilities. Because its hopper is mounted on the wheeled tool carrier frame, less effort is required to lift and lower the toolbar, and the application of fertilizer and planting can be easily combined in one operation.

- We began our first experiments with nitrogen fertilizer labeled with the isotope ^{15}N. Use of this isotope will allow us to distinguish between added fertilizer and the large amount of organic nitrogen already in the soil and thus facilitate measuring the efficiency of fertilizer in SAT cropping systems.

Economics

Research in the Economics Program aims to identify socioeconomic and other constraints to agricultural development in the semi-arid tropics and to evaluate means of eliminating them through technological and institutional changes. In carrying out this research, our economists and social anthropologists work closely with the biological and physical scientists of the crop improvement and farming systems programs.

Village Studies

The Village-Level Studies (VLS) started in six villages of southern India in 1975 have given us a "grass roots" approach to

Village-level studies carried out by ICRISAT in India cover a wide range of subjects. Here the subject of investigation is nutrition.

agricultural research and a data base that provides valuable information for the on-farm experiments we are now conducting in those villages with Indian scientists.

This year, in collaboration with Gujarat Agricultural University, we extended these studies to two villages in Gujarat State, to cover an important groundnut- and pearl millet-producing area in northern India. We also began village studies in West Africa with the posting of two economists there.

We are convinced that the SAT village is the best locus for socioeconomic research and for technology adaptation studies. It is there that we come into direct contact with the farm families our research is designed to benefit, and it is only in the village that real constraints to agricultural development express themselves fully

The original six villages in these studies were selected to furnish a comparison across three broad agroclimatic zones of SAT India. An investigator with a university education in agricultural economics is stationed in each of the villages and collects, on a regular basis, information from selected households and farms.

Studies on risk attitudes, cropping patterns, nutrition, weed management, and the labor market in these villages have all contributed recommendations for priorities in technology development that have helped ICRISAT formulate research strategy. And in the on-farm experiments now going on in these villages, we are able to reach back for "before and after" comparisons that enable us to better measure the progress of our research.

Fertilizer Use in SAT India

In a collaborative study with the Indian Council of Agricultural Research we found that a major reason for low fertilizer use in the nonirrigated areas of SAT India is that high-yielding cultivars of sorghum and millet have not been widely adopted. Where such new cultivars are grown, they do receive fertilizer applications even when the crops are not irrigated. Results from the study therefore contradict the popularly held view that nonirrigated high-yielding pearl millet and sorghum cultivars receive no fertilizer. In 23% of the districts—the major pearl millet-producing districts of India—more than 80% of the farmers using fertilizer applied it to rainfed hybrid pearl millet. And in more than 75% of the sorghum districts, fertilizer was applied to nonirrigated high-yielding sorghum by 80% of the farmers who use fertilizer.

Our findings also make it clear that the local cultivars, which cover most of the area, are largely unfertilized. As new cultivars are adopted on a wider scale, we can expect fertilizer use to increase.

The study confirmed that most of the growth in fertilizer consumption in India in the 1960s and 1970s was in irrigated farming areas. The average level of fertilizer consumption per hectare was 57 kilograms on irrigated land, compared with 18 kg/ha in dryland areas.

On-Farm Watershed Research

For the second straight year our economists and farming systems scientists conducted on-farm experiments in three villages of southern India in collaboration with selected farmers, the All India Coordinated Research Project for Dryland Agriculture, and three agricultural universities. Although total rainfall was below normal and many crops were hit hard by drought stress, cereals yielded well in the ICRISAT watersheds. The production gap between improved and traditional technologies was greater in 1980 than in 1979 when rainy-season crops failed

Farmer, left, discusses his sorghum crop with ICRISAT technicians in cooperative on-farm watershed development experiment in Aurepalle village, India.

in one of the villages and were adversely affected in the other two.

This on-farm research, evolving out of our village-level studies, is centered on three watersheds ranging from 11 to 14 hectares and involving from five to eight farmers in the villages of Aurepalle (red soils), Kanzara (medium deep black soils), and Shirapur (deep black soils). The farmers have participated continuously in planning the work and in development activities. ICRISAT underwrote the scheme by guaranteeing farmers would achieve at least double their normal profits. We also advanced material inputs, which were made available on a timely basis in the villages.

ICRISAT's funding of the project ended this year and farmers will have to pay their own way in 1981. We will study their response at that time to determine their interest in adoption of the various technology options.

Other Highlights

- With farming systems scientists, we completed a comprehensive review of their cumulative research on farming systems components for India. This review, published as ICRISAT Research Bulletin No.2, will

Sorghum samples being harvested from a farmer's field in ICRISAT on-farm experiment at Aurepalle.

guide the approach and choice of sites in future research in the Indian SAT.

- We completed research showing that farmers cannot hire animal draft power as readily as they can hire land and human labor in the six VLS villages. This research suggests that access to a tenant's draft animals is a major reason for leasing out land in SAT India.

- An Economics Program study revealed that only approximately 50% of the potential human labor in the VLS villages is used for work on farmers' own fields and in the daily labor market. This implies that household or other production activities and/ or leisure are a major component.

- We determined that the average rate of involuntary unemployment for females in the VLS villages was 21%, whereas the figure for males was 14%.

- Our studies in Upper Volta showed that the donkey-drawn *houe manga* traction system under farmers' management significantly increased returns to both land and labor over traditional hand tillage. It permitted more thorough weeding and was labor-saving. It was not found to be labor-displacing because its major effect is to increase labor efficiency during the first weeding, which comes at a peak workload period. Moreover, data suggested that area expansion followed adoption of the donkey traction system, increasing the demand for labor during slack periods.

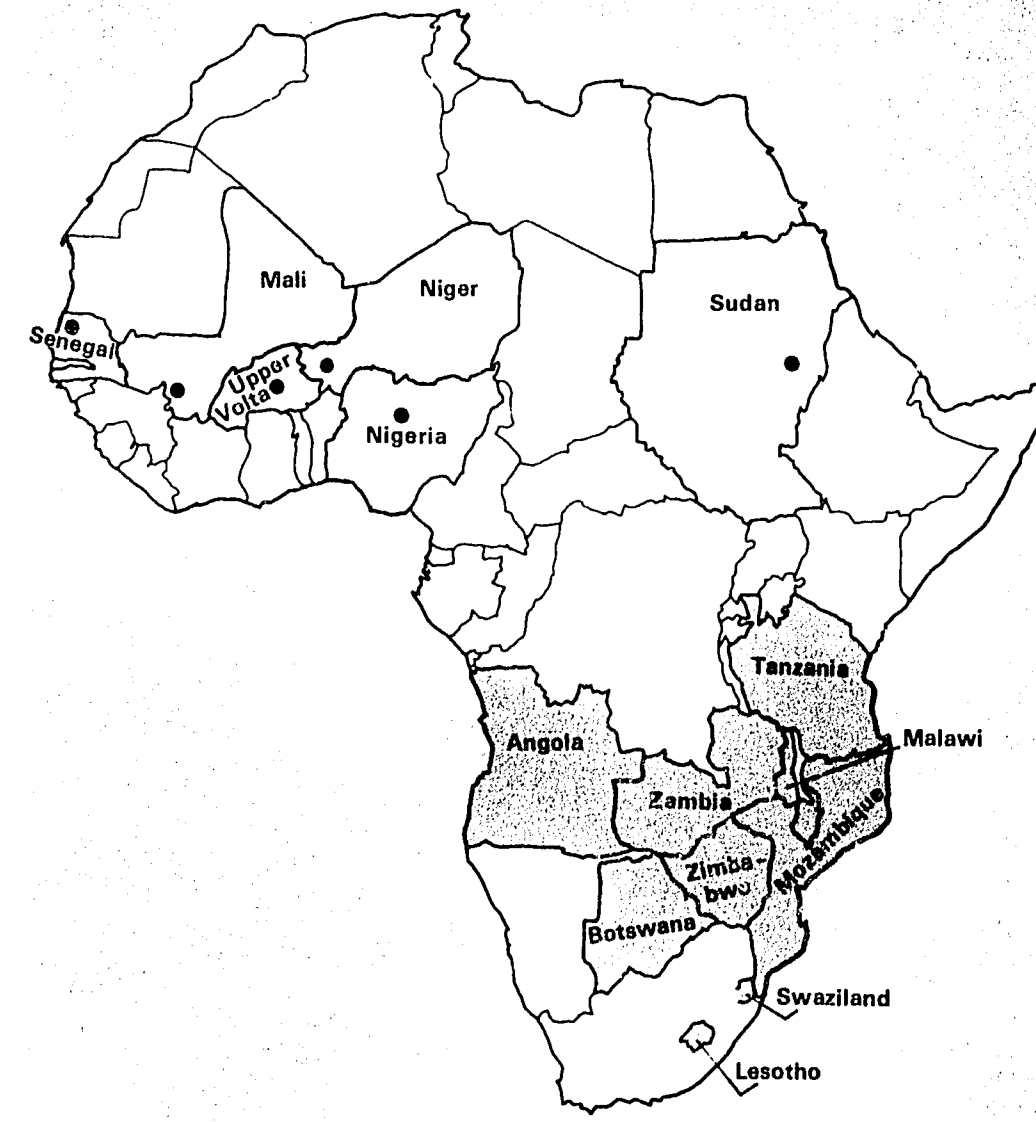
Farmers throughout the SAT have devised a wide range of traditional equipment and farming methods. Bullock power is particularly important in many of these systems.

International Cooperation

Although much of ICRISAT's research has been centered in India—the home of our headquarters and of more than half the SAT's population—we have drawn on worldwide resources and scientific knowledge to improve our mandate crops since the beginning of the Institute in 1972. And, increasingly, we have expanded our own research efforts in countries of the SAT outside of India, especially in Africa.

We had 22 scientists posted in seven countries of Africa at the end of 1980, and next year we will establish a research station in Niger with a team to work on millets and improve farming systems in that vital area of the Sahel. The new ICRISAT Sahelian Center will be our only independent research facility in Africa and eventually will be staffed by ten scientists. In other African countries our scientists are working at the research stations of the national programs, including Kamboinse in Upper Volta, where an

A field of pearl millet germplasm at Kamboinse Research Station in Upper Volta, where ICRISAT has eight scientists working to improve cereal crops and farming systems.



ICRISAT has 22 scientists posted in the countries shown in yellow. Heads of state of nine southern African countries (brown) have invited ICRISAT to establish a regional research center in Botswana to assist in their agricultural development

eight-member interdisciplinary team presently constitutes our largest single research effort outside of India.

In response to an invitation from heads of state in nine southern African countries, we sent a mission of scientists to those countries in November 1980 to determine how ICRISAT might strengthen research on our mandate crops in their areas. The invitation from the Southern African Development Coordination Conference was for us to establish a regional research center in Botswana. Countries in the Conference are Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe.

Our fact-finding scientific team submitted a report to the heads of state and to the ICRISAT Governing Board for discussion and consideration in 1981. Sorghum, pearl millet, and groundnut are important crops in the region.

In Mexico an ICRISAT scientist is working on sorghum lines that may prove useful for high altitudes and for tortillas in drier areas of Mexico and Central America where maize is a marginal crop. And in Syria our scientists are working with those of our sister institute ICARDA to improve chickpeas in the Middle East and North Africa (for impressive early results of this effort see the Pulses section of this report).

We are also investigating possible areas of collaboration on ICRISAT's mandate crops in Thailand, Sri Lanka, and China, but we do not contemplate long-term commitments there. Exchange of breeding material, technology transfer, and exchange of information will be the main areas of cooperation. The work will be mostly in sorghum and groundnut, and in the farming systems associated with those crops.

Africa

Our research in Africa to date has centered primarily on improvement of pearl millet and sorghum, the cereals that sustain life in much of the Sahelian and Sudanian zones. We also have begun work in Africa to improve farming systems associated with those two crops, and within the next 2 years will add groundnut to our research being conducted there. We made significant advances this year in our work in Africa in both sorghum and millet.

Sorghum

In Upper Volta improved sorghum cultivars were extensively tested on farmers' fields for

ICRISAT sorghum DiallelPop 7-862 yielded 2760 kg/ha in 1980 rainy-season trials in Ethiopia, outperforming all other entries. It is now being released to Ethiopian farmers under the name Malkamash.

the first time. Cultivar E-35-1, of Ethiopian origin, which had an average yield of 1850 kg/ha when planted by 25 farmers in 1979, did less well this year in wider ranging tests when compared with local sorghums. The average yields were 1297 kg/ha for E-35-1, compared with 1167 for local cultivars. However, in these tests improved management resulted in highly significant increases both for E-35-1 and the local cultivars.

Another promising cultivar yielded an average of 2130 kg/ha on 18 farmers' fields, 83% more than the local cultivar. And a short-duration cultivar of Indian origin outyielded the local check by 100% in a test in a low-rainfall area with sandy soil.

We also made progress in our efforts to locate resistance to *Striga*, a parasitic weed that attacks sorghum and millet. Two lines showed high levels of resistance at 23 locations in ten countries of Africa, and another performed well in Sudan in both yield and resistance. And we assembled in Upper Volta a collection of African cultivars whose local names indicated that they may have resistance to *Striga*.

We also obtained significant results in trials seeking to identify sources of resistance to leaf diseases of sorghum in West Africa, such as gray leaf spot and sooty stripe. Four lines were unaffected by the common diseases at the four "hot spot" locations where they are most severe.

Sorghum introduced by ICRISAT in Upper Volta is shown in field trial against local sorghum (tall stalks).

In Mali we devised several simple screening tests for drought resistance and made good progress in standardizing quality tests for sorghum used in making tô, a firm gel paste that requires good overnight keeping qualities. Often tô made from introduced varieties lacks quality; for example, the cultivar E-35-1 is acceptable for tô preparation in Upper Volta, but not in Mali where it becomes mushy following a different method of preparation.

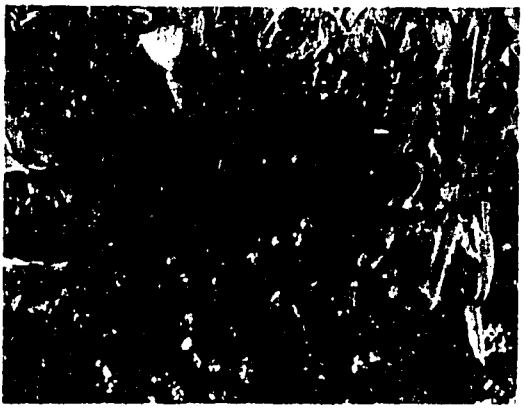
In Sudan we made a major effort this year to evaluate sorghum germplasm collected over the years. All entries of Sudanese origin maintained at ICRISAT Center and all the original local sorghum accessions available at Wad Medani (2071 lines) were planted for proper characterization and documentation. Cross-comparisons revealed that collections at both ICRISAT and Wad Medani were incomplete, and the deficiencies in the collections were corrected. A germplasm collection mission into eastern Sudan yielded 158 wild and cultivated types.

In Tanzania an improved sorghum cultivar originally from Serere, Uganda, performed well for the second straight season, giving a mean yield of over 2700 kg/ha across ten locations.

Pearl Millet

While local landraces of pearl millet in West Africa possess excellent adaptation to their environment and to existing cultivation methods, their yield is limited by such factors as late flowering, excessive plant height, unbalanced tillering habit, partial susceptibility to insects and *Striga*, and insufficient grain accumulation in response to good management.

We are trying to improve these local populations by crossing with them material from other areas that can modify their deficiencies. After 3 years of work on millet improvement in Upper Volta, our breeders presently conclude that the best selections come from crosses where one or both parents are West African, rather than from exotics brought in from other areas.



The parasitic witchweed Striga *(purple flowers) is a destructive enemy of sorghum and pearl millet throughout much of Africa.*

The development of sources of resistance to downy mildew disease was intensified this year. In Mali a useful collection of 375 Malian pearl millet cultivars was screened at two sites; several of these appeared to have low incidence of downy mildew, and 16 others showed no symptoms. In Upper Volta, testing confirmed the resistance to downy mildew in D-1163, which had been found free of the disease in tests at Samaru, Nigeria, in 1978; ten other pearl millet lines were also found to be free of downy mildew in the tests at Kamboinse and Ouahiagouya.

In Sudan, Serere Composite 2, a cultivar of Ugandan origin extensively tested by our program, outperformed the local cultivar for the 3rd straight year and was accepted for prerelease multiplication by the Variety Release Committee of Sudan.

In Senegal both direct introductions and experimental varieties generated from crosses of Senegal and introduced parents did well in trial. IBV-8004, an experimental synthetic variety made at Bambey, gave 41% more yield than the improved local

Pathologist assesses downy mildew incidence on millet lines in Upper Volta.

cultivar in multilocation tests. Two other experimental varieties yielded 31 and 12% more than did the improved local cultivar.

Pest surveys carried out through the semi-arid areas of Upper Volta, Niger, and Nigeria highlighted the seriousness of two millet pests—the earhead caterpillar *(Raghuva albipunctella)*, which was serious even on local cultivars in 1980, and the stem borer *(Acigona ignefusalis)*, whose infestation could reach 85% of stems surveyed.

Other African Highlights

We initiated a program of economics research at the farm level this year. This program seeks to identify and develop improved production techniques through analysis of existing farming systems in West Africa. Both millet and sorghum will be studied in agroeconomic trials. Two principal economists are now on station to carry out this work from Kamboinse, Upper Volta, and Niamey, Niger.

Also, for both sorghum and millet, we have drawn up a list of insect pest species and carried out surveys in several countries, including Senegal, Upper Volta, and Niger, to assess the relative importance of these species in causing damage to the two crops.

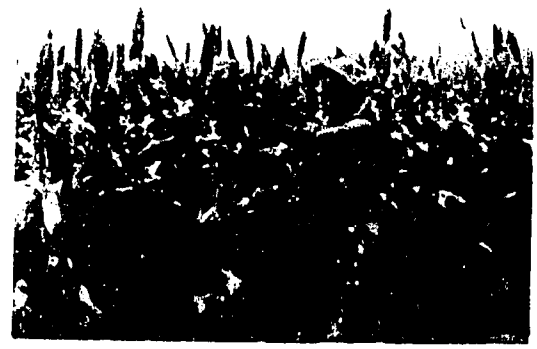
Agronomic work done this year from Upper Volta should also prove beneficial to both crops. Detailed testing of improved cultivars of sorghum and millet was carried out in in the different soil types that occur along slopes. Strong variety/soil-type interactions were observed and will be helpful in our future research.

Latin America

Our sorghum work in Mexico is being carried out by an ICRISAT breeder posted at our sister institute CIMMYT. The main objective is to develop high-altitude, cold-tolerant sorghum varieties with good grain quality for making tortillas and with resistance to the sugarcane borer and fall armyworm, and to leaf diseases.

Initially the germplasm base was diversified by introductions of sorghum from

ICRISAT sorghum breeder posted in Mexico is developing lines for Central America, including types that will grow well at high altitudes and will also be useful in making tortillas.



ICRISAT began village-level studies in Africa this year similar to those conducted in India since 1975. Here an enumerator gathers data from a farmer.

the colder areas of Ethiopia, Uganda, and China; more recent introductions have included additional lines from Ethiopia and some from Yemen. Selections have been advanced and tested in cold-tolerant nurseries. Of 139 lines selected, 122 were white- or yellow-seeded and were considered suitable for human consumption.

Breeding material from the program has been of use in Kenya as well as Latin America, especially at elevations around 1800 meters. The tested material has been sent to 19 locations in 14 countries, and some of it has been incorporated into national sorghum breeding projects. Results obtained from the ICRISAT/CIMMYT program indicate that yields in excess of 4 tonnes/ha can be expected in the highlands of Mexico.

Transfer of Technology

The research carried out by ICRISAT, and the technology developed from it, will mean little if it is not successfully transferred to the scientists and farmers of the SAT and implemented in the field. We assist this process primarily in three ways: (1) by the

work of our scientists in the countries of the SAT alongside scientists of the national programs; (2) by holding workshops and conferences to discuss our research findings with scientists and agricultural officials from throughout the world; and (3) by training agriculturists who will learn this technology firsthand at ICRISAT and take it back into their national programs.

All of these activities come under the heading "International Cooperation" at ICRISAT, and we consider the training function to be one of the most important.

This year 138 agriculturists from state, national, or regional agencies in 27 countries completed training at ICRISAT. More than a third of these were in-service trainees, who come to our research headquarters in India and work alongside our scientists for periods up to 6 months. They conduct their own experiments and they take back to their countries a practical working knowledge of the technology being developed.

We are maintaining contacts with more than 400 of these young agriculturists who completed ICRISAT training programs and are now employed by agricultural agencies in their home countries. Others come for shorter periods or, in the case of research scholars, fellows, and interns, for periods of 1 year or more.

We held international workshops in 1980 on two of our mandate crops, groundnut and pigeonpea, as well as smaller regional meetings on yields gap analysis for dryland crops, microbial inoculants in crop production, sorghum modeling experiments, climatic classification, and special meetings and field days with scientists in national programs who work with our mandate crops.

A Nigerian trainee and his experiment at ICRISAT.

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G. Gunasekera, Soil & Water Scientist, International Cooperation (from July 1980)
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A. Lakshminarayana, Junior Scientific Liaison Officer (Visitors' Services)
S. B. C. M. Rao, Travel Officer (until Nov 1980)
R. Narsing Reddy, Transport Officer
P. W. Curtis, Security Officer
N. Rajamani, Liaison Officer, New Delhi Office (until Nov 1980)
S. Krishnan, Executive Assistant, International Cooperation (from Feb 1980)

Research Programs

Sorghum

L. R. House, Principal Plant Breeder and Leader
L. K. Mughogho, Principal Plant Pathologist
J. M. Peacock, Principal Plant Physiologist
S. Z. Mukuru, Sorghum Breeder, Kilosa, Tanzania (Transferred to Hyderabad Sept 1980)
T. Omori, Sorghum Breeder, Visiting Scientist
C. M. Pattanayak, Sorghum Breeder/Team Leader, Ouagadougou, Upper Volta
K. V. Ramaiah, *Striga* Physiologist, Ouagadougou, Upper Volta
J. A. Frowd, Cereal Pathologist, Ouagadougou, Upper Volta
J. F. Scheuring, Sorghum/Millet Breeder, Bamako, Mali
W. A. Stoop, Agronomist, Ouagadougou, Upper Volta (until July 1980)
Gebisa Ejeta, Sorghum Breeder, Wad Medani, Sudan
Vartan Guiragossian, Sorghum Breeder, Mexico
K. F. Nwanze, Cereal Entomologist, Ouagadougou, Upper Volta
M. B. Boling, Cereal Agronomist (from Oct 1980)
N. G. P. Rao, Plant Breeder, Nigeria (from June 1980)
Bholanath Verma, Plant Breeder
D. S. Murty, Plant Breeder
B. L. Agrawal, Plant Breeder
B. V. S. Reddy, Plant Breeder
M. J. Vasudeva Rao, Plant Breeder
N. Seetharama, Plant Physiologist
R. K. Maiti, Plant Physiologist
K. N. Rao, Plant Pathologist
S. R. S. Dange, Plant Pathologist (until June 1980)
K. V. Seshu Reddy, Entomologist (until Nov 1980)
H. C. Sharma, Entomologist
Ranajit Bandopadhyay, Plant Pathologist (from Sept 1980)
Suresh Pande, Plant Pathologist (from Oct 1980)
S. P. Jaya Kumar, Administrative Assistant (from April 1980)

Pearl Millet

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Aran Patanothai, Principal Plant Breeder (until Oct 1980)
R. J. Williams, Principal Plant Pathologist
S. C. Gupta, Millet Breeder, Bambey, Senegal
A. Lambert, Millet Breeder, Bambey, Senegal (until Apr 1980)
R. T. Gahukar, Cereal Entomologist, Bambey, Senegal
R. P. Jain, Millet Breeder, Wad Medani, Sudan
P. K. Lawrence, Millet Breeder, Ouagadougou, Upper Volta (until May 1980)
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S. O. Okiror, Millet Breeder, Samaru, Nigeria
P. G. Serafini, Agronomist, Bamako, Mali
B. B. Singh, Millet Breeder, Maradi, Niger
N. V. Sundaram, Cereal Pathologist, Samaru, Nigeria
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B. S. Talukdar, Plant Breeder
K. N. Rai, Plant Breeder
S. B. Chavan, Plant Breeder
G. Alagarswamy, Plant Physiologist
S. D. Singh, Plant Pathologist

R. P. Thakur, Plant Pathologist
S. P. Wani, Microbiologist
V. Mahalakshmi, Plant Physiologist
Pheru Singh, Plant Breeder (from Sept 1980)
D. B. Godse, Microbiologist (from Nov 1980)

Pulses

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W. Reed, Principal Entomologist
J. B. Smithson, Principal Plant Breeder, Chickpea
J. A. Thompson, Principal Microbiologist (from Sept 1980)
Hiroshi Hirata, Plant Physiologist (from June 1980)
K. B. Singh, Chickpea Breeder, Aleppo, Syria
H. E. Gridley, Geneticist/Associate Plant Breeder, ICARDA (from April 1980)
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K. C. Jain, Plant Breeder, Pigeonpea
Onkar Singh, Plant Breeder, Chickpea (on leave)
C. L. L. Gowda, Plant Breeder, Chickpea
S. C. Sethi, Plant Breeder, Chickpea
Jagdish Kumar, Plant Breeder, Chickpea
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S. Sithanantham, Entomologist
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M. P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist
O. P. Rupela, Microbiologist
J. V. D. K. Kumar Rao, Microbiologist
Satish Rai, Plant Breeder, Pigeonpea (until June 1980)
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K. P. Goswami, Post-Doctoral Research Fellow (from Oct 1980)
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Groundnut

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J. H. Williams, Principal Plant Physiologist (from Sept 1980)
K. Maeda, Visiting Scientist, Plant Physiology (until July 1980)
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M. Natarajan, Agronomist
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R. S. Aiyer, Administrative Assistant

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Umaid Singh, Biochemist
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V. R. Rao, Botanist

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