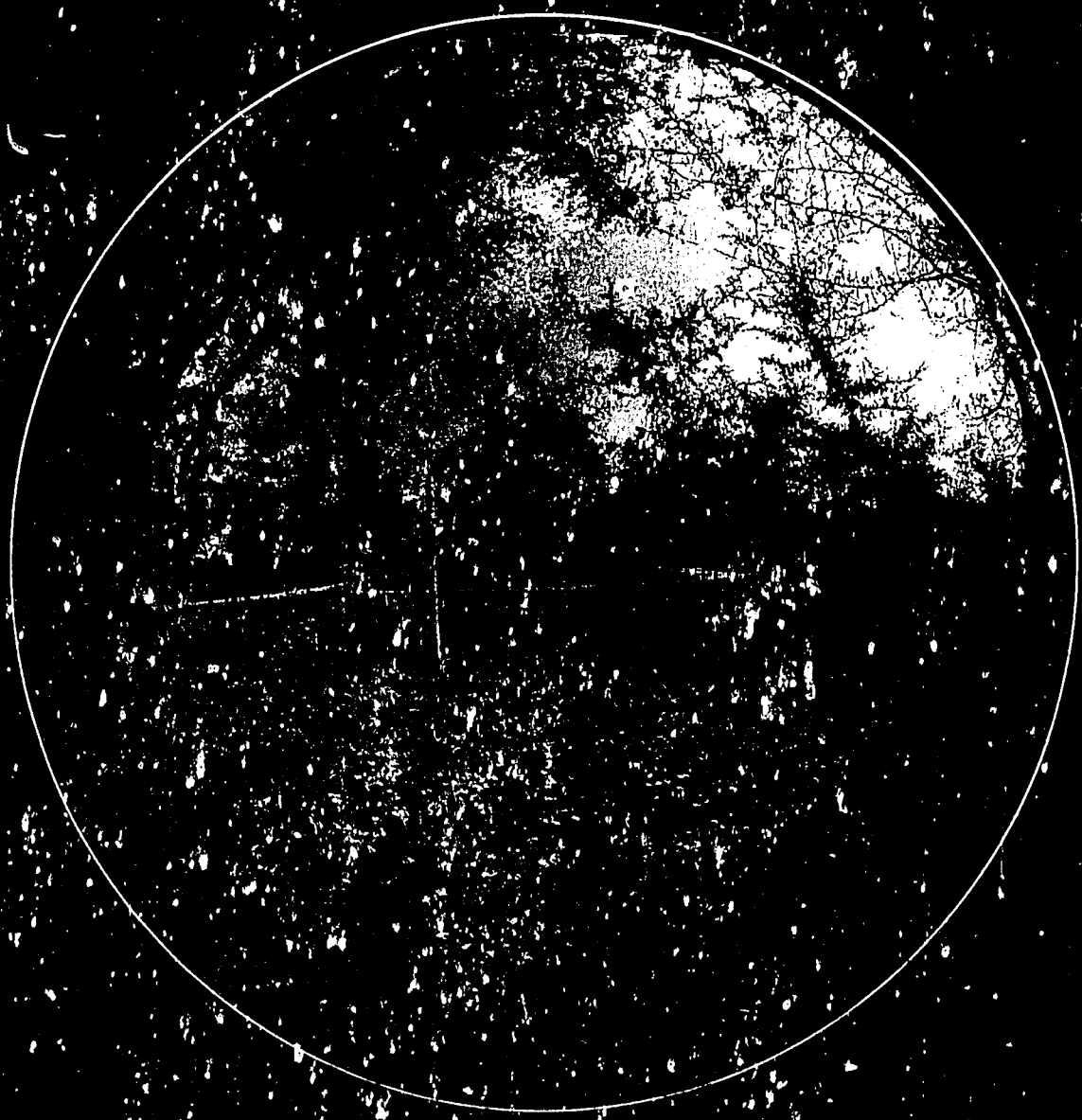
PN-ABE-137

ICRISAT
Research Highlights
1988



Contents

Introduction	1
About ICRISAT	3
Advances in Pathology	4
Environment Challenges: Some Solutions	9
Insights into Control of Insect Damage	12
Achievements in Plant Breeding	15
Insights on Better Resource Management of the Semi-Arid Tropics	22
OPSCAR's Improved Technology for Semi-Arid Tropics of West Africa	30
Transfer of Technology	32
Germplasm Collection Successes	40
Studies on the End Products	43
Other Research Areas	45
ICRISAT Governing Board—1988	47
ICRISAT Senior Staff	48

The International Crops Research Institute for the Semi-Arid Tropics is a nonprofit, scientific, research and training institute receiving support from donors through the Consultative Group on International Agricultural Research. Donors to ICRISAT include governments and agencies of Australia, Belgium, Canada, Federal Republic of Germany, Finland, France, India, Italy, Japan, Netherlands, Norway, Sweden, Switzerland, United Kingdom, United States of America, and the following international and private organizations: Asian Development Bank, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), International Development Research Centre, International Fund for Agricultural Development, The European Economic Community, The Opec Fund for International Development, The World Bank, and United Nations Development Programme. Information and conclusions in this publication do not necessarily reflect the position of the aforementioned governments, agencies, and international and private organizations.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of ICRISAT concerning the legal status of any country, territory, city, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Citation: ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Research Highlights 1988. Patancheru, A.P. 502 324, India: ICRISAT.

Cover: *The environmental effects of trees on crops and livestock are of global concern to agroforesters in their efforts to improve sustainability in agriculture. Collaborative studies conducted by the Central Research Institute for Dryland Agriculture of India and ICRISAT at the Hayatnagar farm, near Hyderabad, in 1988 centered on the introduction of multipurpose trees that exhibit no adverse effects on dryland crops. This fisheye view of the experimental plot shows* Faidherbia albida *(foreground), which is an exotic tree species to the local environment, and* Albizia lebbek *(background) a native tree, both growing alongside castor, a dryland crop.* (Photograph: C.K. Ong)

Introduction

This year ICRISAT made good progress in assisting in the development and transfer of technology to farmers of the semi-arid tropics through cooperation with national programs. ICRISAT's suggestions for improved cropping systems were tested and assessed in West Africa and in India.

In an operational scale research project, ICRISAT Sahelian Center, in partnership with the Institut national de recherches agronomiques du Niger and, more recently, with the Institut d'économie rurale of Mali, has been testing components and combinations of technologies that researchers expect will help ensure more stable and sustainable agriculture in the drier regions of West Africa. In India, groundnut trials were conducted by several Indian state Departments of Agriculture and monitored by ICRISAT's Legumes On-Farm Testing and Nursery unit in several Indian states. Results of both these activities have been most encouraging.

During the year, several improved plant materials developed by ICRISAT scientists, or seeds bred from these materials, reached farmers' fields in all five continents.

This year, too, new cost-saving methods in pathology and entomology were developed and utilized by ICRISAT researchers.

One of ICRISAT's networks—the Asian Grain Legumes Network—established a few years ago evolved beyond the bilateral into the multilateral stage when representatives of its member countries met in Indonesia to suggest ways to improve groundnut production in Asia.

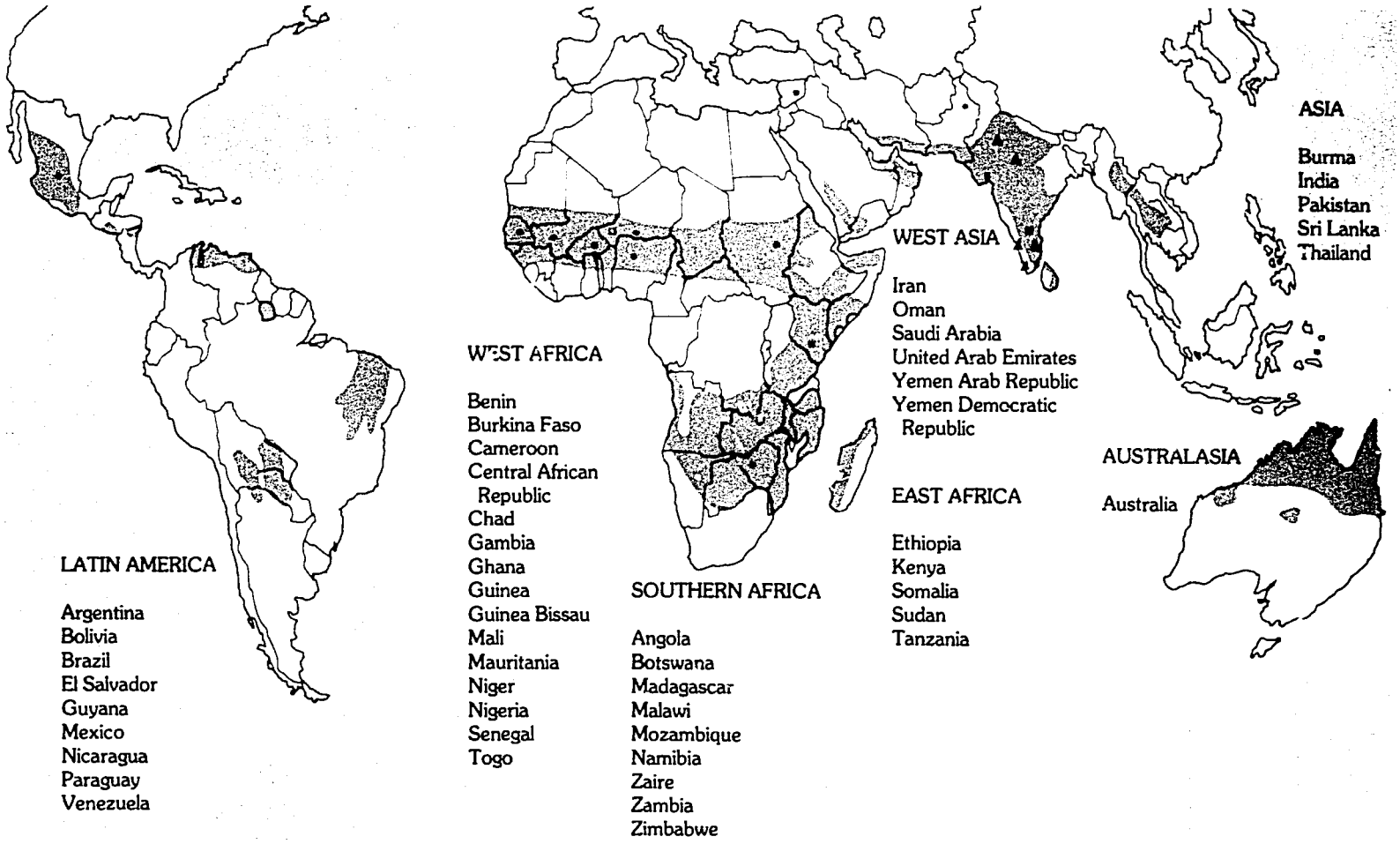
Keeping in view environmental concerns, ICRISAT's agroforestry research has begun to focus on perennial pigeonpea, which was found more suitable than *Leucaena leucocephala* for sowing with crops under Indian semi-arid tropical conditions.

With good rains this year, ICRISAT's improved technology, which continued to be disseminated to the farmers, was utilized adequately with excellent results for the first time in 4 to 5 years. We, therefore, look forward to the future with renewed strength.

L.D. Swindale
Director General

Pods of an ICRISAT groundnut variety ICGS 44 (ICGV 87128); the variety was released in Gujarat, India, in 1988.

ICRISAT's chickpea variety ICCV 1 growing in Nepalgunj, Nepal, under its release name Sita.



Semi-arid areas (in yellow) *covered by ICRISAT's mandate. Green squares indicate location of ICRISAT Center in India and Sahelian Center in Niger; red dots indicate collaborative research stations where ICRISAT scientists have been posted; and red triangles indicate ICRISAT's cooperative research stations in India.*

About ICRISAT

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

The seasonally dry semi-arid tropics are spread over nearly 20 million square kilometers and cover all or parts of 50 nations on five continents. They include much of South Asia, parts of Southeast Asia, West Asia, and Australia, two wide belts of Africa, areas of South America and Central America, and much of Mexico.

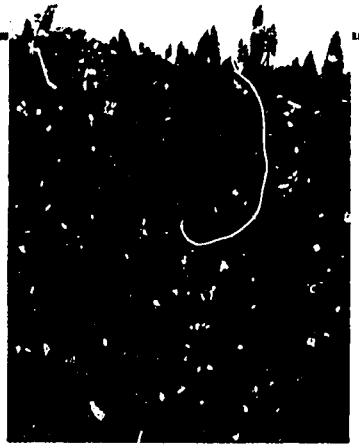
The SAT is a harsh region of limited, erratic rainfall and nutrient-poor soils. It is populated by over 750 million people, most of whom live at subsistence levels and depend for their food on the limited production of small farms.

The crops researched by ICRISAT are sorghum and pearl millet—two of the major cereals in the SAT—and chickpea, pigeonpea, and groundnut, the most important food legumes of the region. Groundnut, rich in oil, is also an important cash crop for the SAT farmer. The four others are all primarily subsistence food crops; over half the total production of each—in some places nearly all of it—is consumed on the farms where it is grown. ICRISAT's headquarters are at Patancheru, India, 26 km northwest of Hyderabad, but it also has scientific staff posted in seven countries of Africa, in Mexico, Pakistan, and Syria, and at five cooperative research stations of agricultural universities in India. Principal operations in Africa are in Kenya, Malawi, Mali, Niger, Nigeria, and Zimbabwe. Scientists were previously posted also in Senegal, but funding for these positions has ceased. This year, ICRISAT drew its operations in Burkina Faso to a close and several ICRISAT staff were transferred from there to Bamako, Mali, where a part of the West Africa regional program for sorghum was initiated this year. The other part of the program is located at Kano, Nigeria.

The two main bases for ICRISAT's work in Africa are at the Sahelian Center near Niamey, Niger, and the SADCC/ICRISAT sorghum and millets improvement program at Matopos, near Bulawayo, Zimbabwe, set up in response to an invitation from the nine-nation Southern African Development Coordination Conference (SADCC).

ICRISAT's mandate is to:

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



Sorghum variety Framida exhibiting gray leaf spot disease symptoms at Farako Ba, Burkina Faso.

Advances in Pathology

Good rains in the semi-arid tropics are often associated with a good crop. But good rains alone do not always ensure a good crop. A happy farmer can soon become a sad one when he sees his crop attacked by any one of the many diseases caused by fungi, bacteria, viruses, and nematodes. These diseases can reduce the potential yield of the crop, and sometimes even destroy it completely.

Scientists at ICRISAT are constantly developing improved breeding material that contain resistance to some of these diseases prevalent in specific areas.

Ergot (*Claviceps sorghi*) is a fungal disease of sorghum that causes considerable problems for hybrid-seed producers in India, Thailand, Zambia, and Zimbabwe. Ergot is also a yield reducer in cultivated sorghum in Asia and Africa. This year, scientists at ICRISAT Center were able to elucidate the process of infection and colonization of sorghum flowers by the ergot fungus, which may lead to greater understanding of the mechanisms of ergot resistance than at present and eventually to its control. Fungal spores infect flowers through the stigma, which normally receives pollen. Upon gaining entry into the stigma, the fungus grows down the stalk that connects the stigma with the seed-bearing part of the flower (ovary), and then on to the ovary itself. The growth route is similar to that followed by the growth of the pollen. The fungus grows in the ovary and replaces it with a fungal mass. This fungal mass exudes honeydew containing millions of spores (conidia).

Honeydew, which has turned white because of the presence of secondary conidia, on a cut, ergot-infected sorghum panicle (center); electron micrographs of round microconidia growing on elliptical, big spores or macroconidia (left) and secondary conidia on honeydew surface (right).

A farmer in Rwanda looks at her ergot and smut infected sorghum.

The honeydew was known to contain only one type of spore called macroconidia (elliptical, big spores). In 1987, ICRISAT scientists in collaboration with Imperial College, London, discovered in Zimbabwe another spore type, which they called secondary conidia formed by germinating macroconidia. In 1988, at ICRISAT Center, scientists discovered in the honeydew small round spores, which they called microconidia. They also confirmed the occurrence of secondary conidia in India, and proved that all the three spore types can infect sorghum.

ICRISAT scientists also investigated the production of secondary conidia. At 15-28°C and at over 90% humidity, the honeydew surface became firm and on it a whitish growth appeared. Microscopic examination revealed that the firmness of the honeydew was because of a fungal mat formed by intermingling of hyphae originating from big spores germinating on the surface of the honeydew. Some big spores in the mat germinated by producing erect spore-bearing fungal parts on which spores (secondary conidia) were not held firmly. These findings suggested that the spread of the disease could be by wind as well and not just by rain splashes and insects.

Studies at ICRISAT Center showed that unlike ergot (*Claviceps fusiformis*) in pearl millet, fertilized sorghum ovaries were colonized by sorghum ergot. Pollination did not completely exclude the fungus from infecting developing grain.

In West Africa, ICRISAT scientists continued to study the gray leaf spot (*Cercospora sorghi*) disease of sorghum. This disease is severe in the top four leaves of most susceptible sorghum genotypes, under natural infec-

Pale green banding on sorghum leaves, a symptom caused by a virus related to maize stripe virus.

tion conditions, when grains approach maturity. The implications of the disease on yield are under study.

Studies continue on downy mildew (*Peronosclerospora sorghi*), a disease that attacks sorghum in Asia, Africa, and America. Results of experiments by ICRISAT scientists indicate that the downy mildew pathogen attacking sorghum in Golden Valley, Zambia, may be more aggressive than that at Matopos, Zimbabwe, or in Texas, USA. Differences in pathogen isolates were also noticed between Golden Valley and ICRISAT Center.

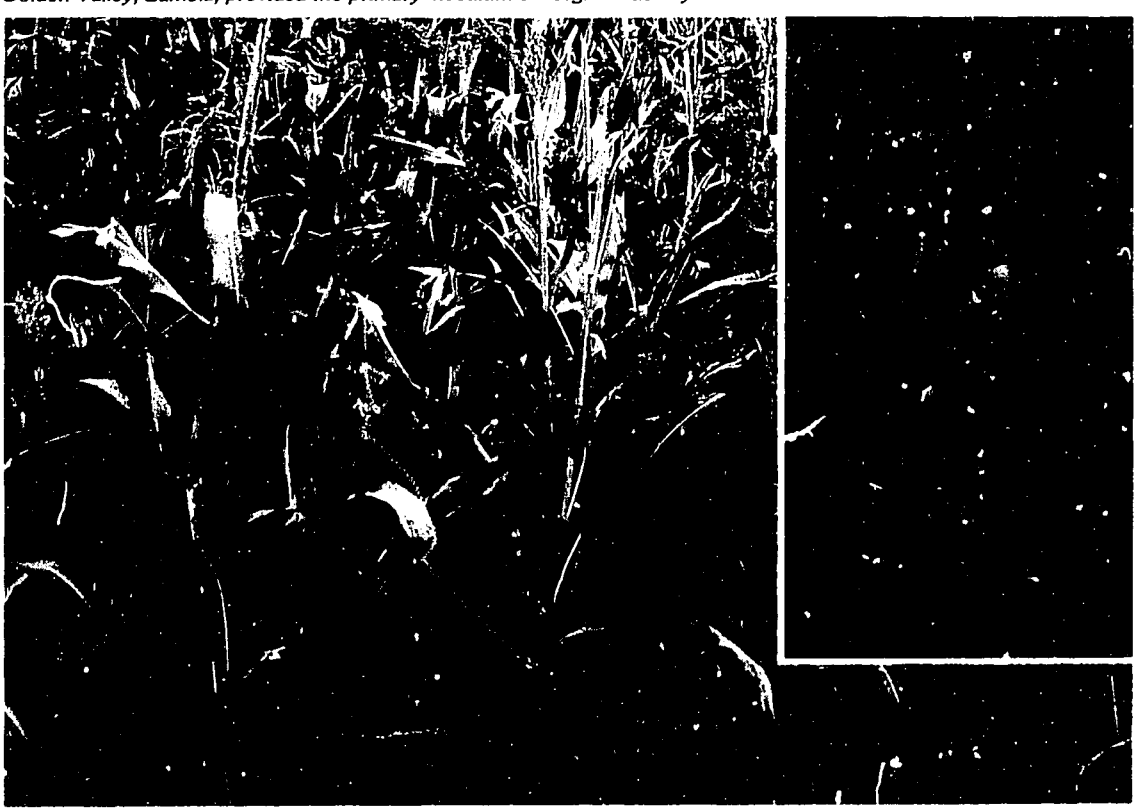
ICRISAT scientists, this year, were able to identify a rhabdovirus (a bullet-shaped virus), similar to maize mosaic virus, as the cause of the sorghum disease with mosaic symptoms on the plant leaves. This is a major step forward in combating the disease.

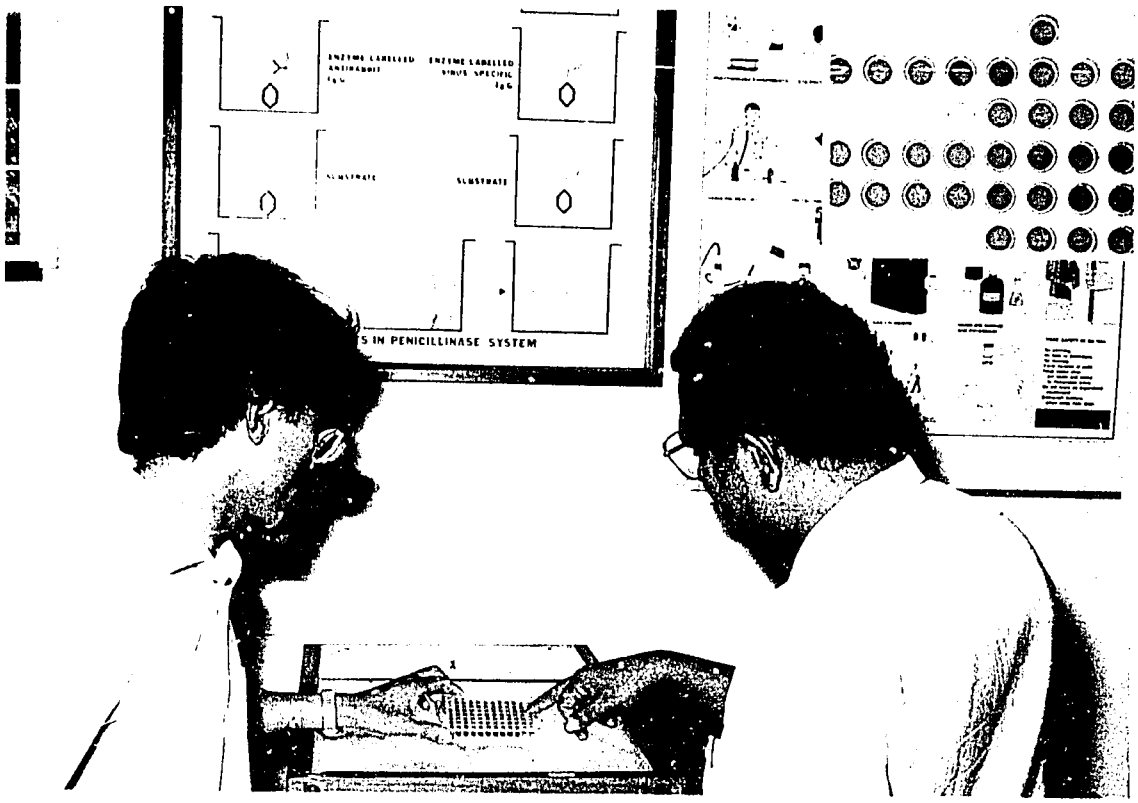
ICRISAT researchers were also able to establish that the virus was transmitted by an insect known as the plant hopper (*Peregrinus maidis*) and that the viral infection in sorghum was more severe than in maize.

Chlorotic (pale green) lines with streaks on sorghum leaves have been reported for more than 50 years in India and their causal agents had never been identified.

A virus—related to the maize stripe virus—was identified as the cause of the chlorotic bands on sorghum leaves. This caused more damage of infected plants than the maize mosaic virus in sorghum. Greenhouse

*Sorghum attacked by downy mildew in a farmer's field in Rwanda while this wild sorghum plant (*inset*) growing 26 km from Golden Valley, Zambia, provided the primary inoculum of sorghum downy mildew.*





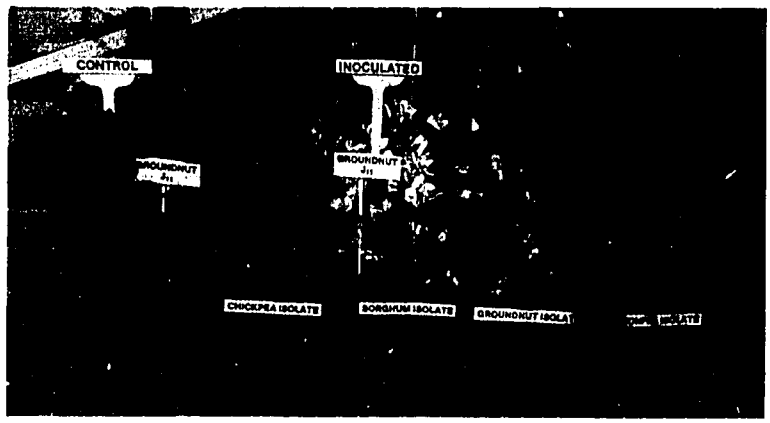
An ICRISAT scientist (right) discusses with a trainee the ELISA test developed at ICRISAT Center in which a distinct color change occurs. A blue reagent in the wells of the plate (inset) turns green when the virus is present and yellow when the virus is present at a high concentration.

experiments on sorghum plants at ICRISAT Center during 1988 have established that this stripe virus is also transmitted by the same plant hopper.

Identification of viruses, however, is a difficult and costly process. At least this was so until the very recent past. Researchers working at ICRISAT Center, in continuing efforts to improve methods for detection of plant viruses, have standardized a method for an enzyme-linked immunosorbant assay (ELISA) using material available in India and other such developing countries. This method costs less than one-fifth that of any conventional method. Unlike other enzyme systems used in ELISA, presence of the virus is marked by a distinct color change and not by variations in the shades of a single color.

This year's breakthrough resulted from an idea put forward in 1978 by an Indian scientist working in a research institute in Bombay. The idea did not get adequate recognition. ICRISAT scientists used a new dye system to indicate the reaction and standardized the method.

This ICRISAT method uses penicillinase, an enzyme found in bacteria that converts penicillin into penicilloic acid. The conventional enzymes currently used in the ELISA tests are alkaline phosphatase, horseradish peroxidase, and urease, which are costly and not easily available in devel-



Effect of various isolates of dry root rot pathogen on a groundnut genotype in a greenhouse study at ICRISAT Center.

Response to inoculation with dry root rot pathogen on the shoot and root mass of a chickpea genotype (right) compared to a noninoculated control (left).

oping countries. Some of their substrates have potential cancer-producing properties and are hazardous in their hydrolyzed forms, if handled carelessly. Therefore, the ICRISAT method is cost saving, safe, and ideal for developing countries.

ICRISAT researchers found that certain penicillins cannnot be used in ELISA. However, the sodium and potassium salts of penicillin that can be used are easily available in India and several other developing countries.

Researching diseases of pearl millet, ICRISAT scientists were able to establish the existence of distinct pathotypes of the downy mildew pathogen, *Sclerospora graminicola*, on the crop in India and in West Africa. This finding has implications on breeding pearl millet lines for resistance to the disease. It also has implications for the vulnerability of resistant cultivated varieties, since lines resistant to one pathotype of the disease may not be resistant to another.

Similarly, in studies on the sterility mosaic disease of pigeonpea, the pathogen/vector was found to have distinct strains in India. The disease and its vector, *Aceria cajani*, were reported to survive on volunteer and summer pigeonpeas during the off-season in some parts of India.

Groundnut breeding lines previously found resistant to late leaf spot disease at ICRISAT Center, India, were also resistant to this disease when tested at ICRISAT Sahelian Center in Niger, West Africa. They significantly outyielded local cultivated varieties that are susceptible to the disease.

At Chitedze, Malawi, all the groundnut varieties resistant to groundnut rosette disease were tested by scientists of the Southern African Development Coordination Conference (SADCC)/ICRISAT Groundnut Improvement Program and found susceptible to the groundnut rosette assister virus but not to groundnut rosette virus and its satellite virus. All these viruses cause the disease.

No significant differences were found in the pathogenicity of isolates of dry root rot pathogen (*Rhizoctonia bataticola*) from sorghum, pearl millet, groundnut, chickpea, or pigeonpea. However, the cropping systems were observed to influence the pathogen populations in the soil. Intercropping of pigeonpea with sorghum or cowpea resulted in higher counts of resting bodies (sclerotia) of the fungus in the soil.

Environmental Challenges: Some Solutions

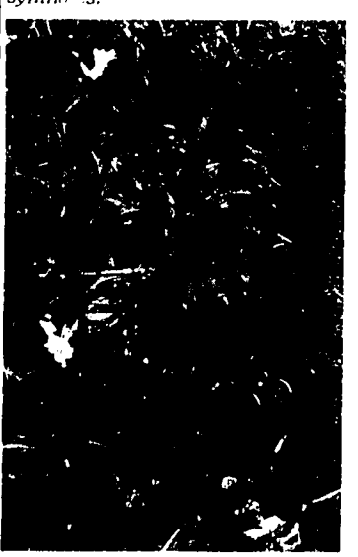
Insufficient and sporadic rainfall reduces the scope of agriculture in the semi-arid tropics. Agricultural scientists must also grapple with other environmental factors inhibiting good crop production, such as high soil and air temperatures, long periods of drought in some places and periods of low temperatures in others, effects of daylength or even low night temperatures on crop yield, and implications of latitudinal changes. In the process of learning to ameliorate such effects on crop yield, scientists also study the mechanics of plant growth.

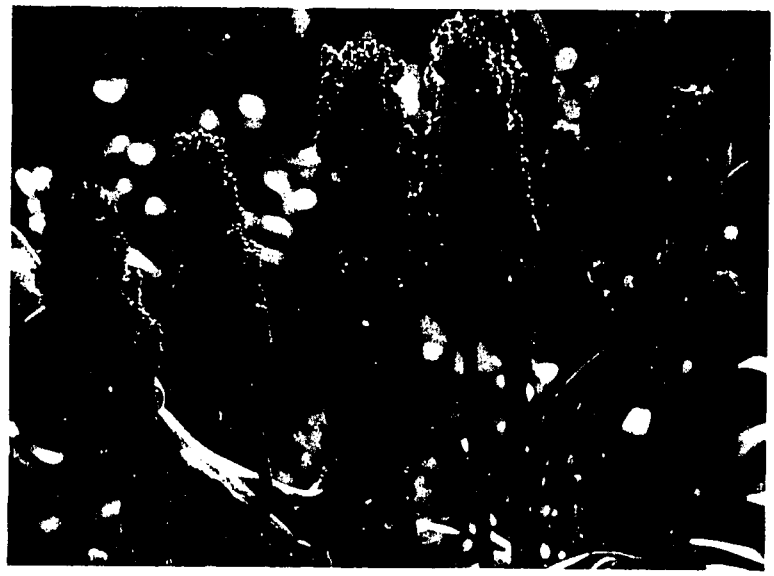
Studies on the behavior of sorghum and pearl millet genotypes under heat stress were undertaken at ICRISAT Center during 1988. ICRISAT scientists found that sorghum produced fewer heat-shock proteins (proteins synthesized in the tissue in response to above-optimum temperatures) than pearl millet when grown under simulated high temperatures. However, as in sorghum, no significant difference was found among contrasting lines of pearl millet. The implications of such differences between sorghum and pearl millet are now under investigation.

In another study on sorghum using radioactive carbon, ICRISAT scientists established that sorghum lines that stay green and thus resist lodging

Studies on the behavior of pearl millet genotypes under simulated heat stress conditions, at the growth point of the seedlings near the soil crust.

Radioactive carbon dioxide being fed on penultimate sorghum leaves in studies (below) on movement of photosynthates within a plant and a radioactivity counter (left) being used to monitor movement of photosynthates.





One of the better white-seeded low-temperature tolerant sorghum varieties developed by ICRISAT's Latin American Sorghum Improvement Program growing in Mexico.

at maturity hold a greater proportion of recently produced assimilates in their stems than elsewhere. This research was carried out by examining partitioning of recently produced assimilates into plant parts at different stages of plant development. The penultimate leaf was exposed to $^{14}CO_2$ at midday and the radioactivity was then determined 48 hours after feeding $^{14}CO_2$ and at physiological maturity. It was also clear that movement of the photosynthates to the panicle is slower in lines that resist lodging at maturity than in senescing lines.

Experiments in Latin America by ICRISAT scientists indicated that early-maturing and low-temperature-tolerant cultivated sorghum varieties are required for high and stable sorghum grain yields in the Mexican highlands.

In experiments repeated over 2 years on pearl millet seedlings, it was found that seedlings can better withstand high soil temperatures if soil moisture is adequate than when it is inadequate. Results from these studies showed that in the Southern Sahelian Zone of Africa, the combination of moisture and temperature stresses is very detrimental to seedling survival and affects the chances of a good crop stand.

Another observation by ICRISAT scientists on pearl millet was that lower seed quality of aged seed-lots delayed emergence and reduced the final percentage of emerged seedlings. Seed-lots with slower emergence rates also had lower survival percentages of emerged seedlings.

Studies on pearl millet revealed that evaluation of a genotype's performance by its grain yield, and the ratio of grain yield to panicle yield at harvest, is different for locations which are either under drought stress after flowering or have no drought stress. The genotype assessment in locations under drought is therefore not necessarily valid for locations without any drought stress.

In pigeonpea research, however, there was good news... Adaptation of extra-short-duration pigeonpea genotypes to higher latitudes was found feasible when sowing was carried out in May, since the genotypes matured prior to lethal frosts in parts of South Korea and the USA in October.

For groundnut scientists, photoperiod sensitivity is a major consideration in groundnut adaptation to varied environments. Groundnut pod yields were reduced under long-day conditions in more than half the lines tested. However, two ICRISAT lines released in India, ICGS 11 and ICGS 44, were found photoperiod insensitive.

ICRISAT scientists studying drought-tolerant chickpea found that the plants had longer roots and greater root volume than genotypes that were intolerant of drought. Genotypes tolerant of drought had smaller leaves but larger (or double) pods than other genotypes.

In another study, yield increases between 10% and 40% were achieved by making chickpea canopies more erect. This was done by tying up the branches of each plant to increase light penetration. These results suggest that scope exists to improve the canopy structure of chickpea genotypes with a bushy habit, and that the erect canopy guarantees the most efficient light utilization. This finding implies that a favorable change in growth habit could lead to increased yields in chickpea.

Low night temperatures in northern India, in December and January, lead to failure in pod-set, which in turn leads to a low harvest index. ICRISAT scientists this year made selections at Hisar, Haryana (in northern India), for tolerance of low temperatures during flowering and pod-set. This work is expected to contribute to higher yields in the region that will be associated with improved harvest indexes. ICRISAT scientists are now investigating the agronomic practices appropriate for realizing the yield potential of these low-temperature-tolerant genotypes, and utility of these genotypes in other environments.

ICRISAT's extra-short-duration pigeonpeas, growing in a trial at Central Ferry, Washington state, USA, showed adaptibility to higher latitudes.

Spodoptera litura, *an insect which ravages groundnut leaves.*

Insights into Control of Insect Damage

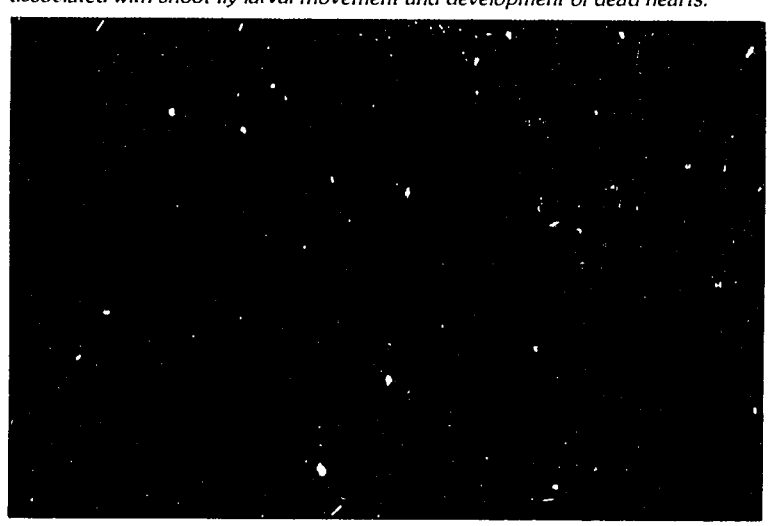
Insect damage contributes to crop loss in all environments. ICRISAT scientists strive to stabilize yields of its mandate crops by improving the plant's ability to withstand insects that ravage them. To do this, it is necessary to understand the mechanics of insect behavior.

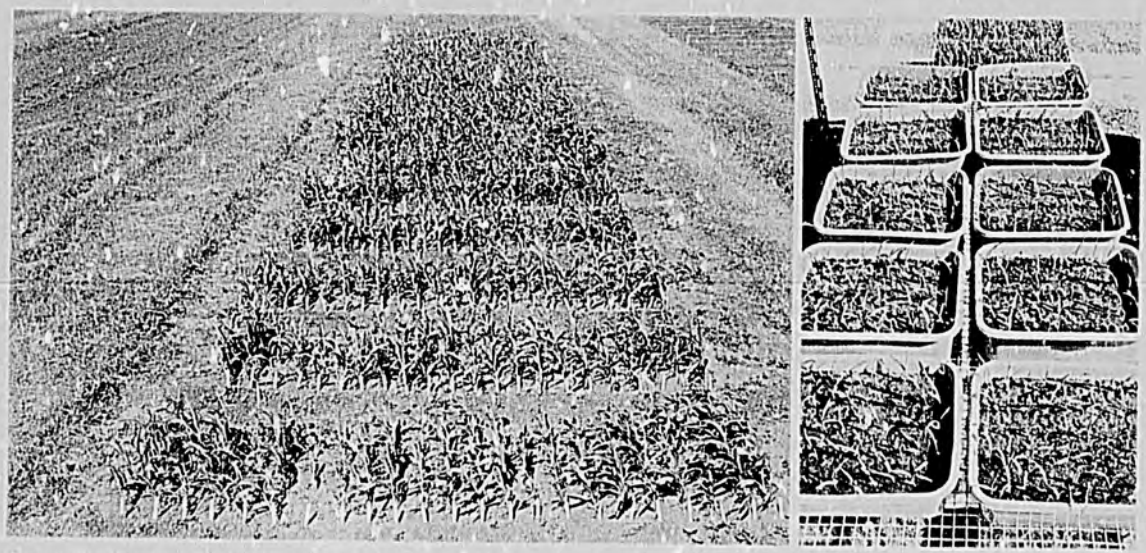
Shoot fly (*Atherigona soccata*) is an insect pest of sorghum. Considerable progress was made during 1988 in studies on shoot-fly behavior and its association with wetness of sorghum leaves. Low leaf surface wetness was associated with sorghum lines resistant to the shoot fly. Leaf surface wetness was low in glossy resistant lines but high in glossy susceptible lines, indicating that low leaf wetness is associated with shoot-fly resistance.

Scientists at ICRISAT Center this year developed a new method of screening large numbers of sorghum lines for resistance to the spotted stem borer (*Chilo partellus*). The existing method of artificially infecting sorghum plants in the field with larvae of the stem borer requires several crop seasons and resources to evaluate hundreds of genotypes. The new rapid screening method, by contrast, is effected by planting seedlings in trays or in field microplots and evaluating these under artificial infestation using a "bazooka" applicator. Screening time is drastically cut and can be completed within 4 weeks of planting. Although seedling resistance does not always indicate resistance at later stages of growth, this method helps eliminate genotypes susceptible at early stages of growth. Large collections can thus be easily evaluated over short periods of time throughout the year, saving on quantity of larvae and carriers as well as reducing the plot size.

An important observation on ovipositional preference of the stem borer on 4-week-old sorghum plants was that younger seedlings (1-week-old to

Leaf surface wetness, as in this central shoot leaf of a sorghum seedling, has been associated with shoot fly larval movement and development of dead hearts.





Screening time to evaluate stem borer resistance of hundreds of sorghum lines was reduced to 4 weeks by planting them in field microplots (left) or trays (right).

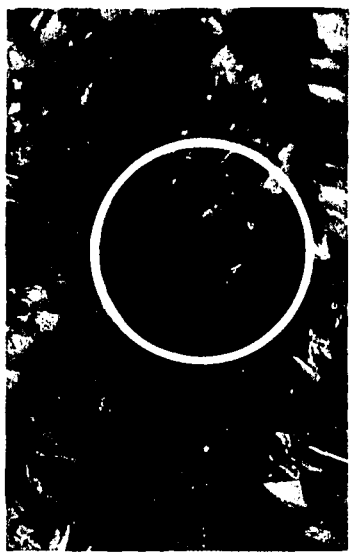
3-week old) were least preferred. Because this trend was consistent in both resistant and susceptible genotypes tested, implications for field screening and for the control of stem borer are crucial.

Two sorghum lines, ICSV 700 and IS 2205, showed significantly lower leaf feeding damage by stem borer than IC3V 1 (CSV 11), a susceptible variety, under various pest densities and crop growth stages.

Head bug (*Calocoris angustatus*) can cause considerable grain yield loss on improved sorghum varieties and hybrids, such as CSH 1, ICSV 1 (CSV 11), and CSH 5. The loss in ICSV 1 grain yield was found to be 89% in field experiments. The sorghum hybrid CSH 1 suffered 70% grain yield loss while the hybrid CSH 5 incurred 56% loss from head bugs.

In Africa, postharvest losses of sorghum grain to insect pests are a serious problem. Grain weevil (*Sitophilus* spp) is found in rural storage bins. ICRISAT scientists in southern Africa began screening breeding material and germplasm for resistance to grain weevil.

High levels of insecticide resistance were found in pod borer (*Heliothis armigera*) samples collected from ICRISAT Center pigeonpea plants. The upsurge on pod borer resistance to synthetic pyrethroids (insecticides) at the end of 1987 and the dispersal of resistant insects were studied by ICRISAT scientists in collaboration with the Overseas Development Natural Resources Institute, UK. Pyrethroid resistance was suspected first when insecticides used on cotton crops failed in coastal Andhra Pradesh, India. Samples of the insects taken at ICRISAT Center between October 1987 and March 1988 showed increasing levels of pyrethroid resistance where none had previously been recorded. Circumstantial evidence exists for repeated influxes of resistant insects from the cotton growing regions some 250 km distant, carried to ICRISAT Center fields by the prevailing southeasterly winds.



Head bug (within circle), *an insect that causes as much as 89% yield loss on cultivated sorghum varieties.*

Analysis of the numbers of pod borers caught in pheromone traps (devices containing a chemical to attract male moths) over the Indian subcontinent during the years 1981-87 indicated regional variations. Obvious changes occurred according to latitude. The period of peak activity of these moths also varied with the locations, in studies conducted in the 1987/88 cropping season. Nepal and Ethiopia have also been included in the international *Helicoverpa (Heliothis) armigera* pheromone trap network.

Studies at ICRISAT Center this year showed that the groundnut plant's vulnerability to defoliation by the insect *Spodoptera litura* decreases as the crop matures; the responses to defoliation in the rainy season differ from those in the postrainy season; and in the rainy season even 58% defoliation caused by as many as five larvae per plant does not cause a significant reduction in pod yield.

Analyses of insect pests of groundnut in southern Africa mentioned in *Research Highlights 1987* were completed and summarized. The finding concluded that white grubs are important insect pests in Malawi and Zimbabwe, termites in Botswana, and pod borers (including *Dorylus* sp, an ant not previously recognized as a groundnut pest) throughout the region.

The first pheromone trap in Ethiopia, a country included in the international Helicoverpa (Heliothis) armigera *pheromone trap network in 1988, near a chickpea plot at Debre Zeit.*

Achievements in Plant Breeding

A dwarf pigeonpea plant developed at ICRISAT Center.

Hard work by ICRISAT scientists, especially breeders, over several years is rewarded when their breeding material reaches the farmers in the form of an approved release for general cultivation, endorsed by a government body. ICRISAT's cooperative efforts with national programs contributed to the release of several such materials in different parts of the world. The process of release of such material often involves adaptation or further development within national programs.

Sorghum materials from ICRISAT were especially successful in India and Latin America in 1988. While one sorghum variety, ICSV 112 (SPV 475), was released as CSV 13 for general cultivation in India by the Indian Central Sub-committee on Crop Standards, Notification, and Release, another ICRISAT variety, ICSV 145, was also released as SAR 1 in *Striga*-endemic areas of India. ICSV 112 matures in about 115 days; it was released as SV 1 in Zimbabwe and as UANL-1-187 in North Mexico earlier. It has given consistently high grain yields of over 3.4 t/ha in the All India Coordinated Sorghum Improvement Project (AICSIP) advanced yield trials from 1982 to 1985. ICRISAT's sorghum hybrid ICSH 110 entered

ICRISAT sorghum variety ICSV 112, released as CSV 13, growing in a farmer's field in Sholapur district, Maharashtra, India.

ICSH 110, an ICRISAT sorghum hybrid, looks promising in advanced trials at Suwan Farm, Thailand.

ICRISAT sorghum hybrid trials at Bagauda, near Kano, Nigeria.

ICRISAT's pearl millet variety MP 124 (ICTP 8203), released in two Indian states, growing in a seed multiplication plot at ICRISAT Center.

minikit trials in India and is to be tested in farmers' fields in the rainy season.

Elsewhere in the world other ICRISAT sorghums also entered farmers' fields.

In Latin America, an ICRISAT sorghum variety was released as INIAP 201 in Ecuador, while an ICRISAT sorghum hybrid was released as AGROCONSA 1 in El Salvador.

ICRISAT varieties outperformed local controls in adaptive trials in Burma, India, Pakistan, the Philippines, Somalia, Thailand, and Vietnam.

In advanced hybrid trials at Kano, Nigeria, two ICRISAT sorghum hybrids, ICSH 507 and ICSH 780, gave more than double the yield of the local control variety Samsorg 17 (SK 5912). ICSH 507 yielded 3.99 t/ha and ICSH 780 yielded 3.89 t/ha, while the control only yielded 1.41 t/ha. In Zimbabwe and Botswana, four ICRISAT Center sorghum hybrids outyielded the local hybrids. In Kenya, evaluation of sorghum varieties for adaptation progressed with the selection of four high-yielding varieties for their resistance to maize dwarf mosaic virus and leaf blight.

ICRISAT scientists at the SADCC/ICRISAT Sorghum and Millets Improvement Program assisted Botswana's national program in determining crossability between cultivated sorghum and columbus grass (*Sorghum almum*), an important forage grass in that country. A 2-year study reported that cultivated sorghum would cross with columbus grass, resulting in the gradual deterioration of the sorghum crop. However, in this process the deleterious traits of seed shattering and disease susceptibility in columbus grass were transferred to the sorghum grain.

There was good news for ICRISAT pearl millet breeders as well this year. ICRISAT pearl millet variety MP 124 (ICTP 8203) was released in Maharashtra and Andhra Pradesh states in India by the Central Subcommittee on Crop Standards, Notification, and Release. It has large seeds, matures early (75 to 80 days), tolerates drought, resists downy mildew, and outyields WC-C75 by about 7% in Maharashtra and 11%

Harvested seed of ICRISAT's released short-duration pigeonpea line ICPL 151, grown in rotation with rice, laid out to dry at Aurepalle, Andhra Pradesh, India.

An ICRISAT breeder (right) discusses seed multiplication of an ICRISAT chickpea variety identified for release with Nepal's Asian Grain Legumes Network coordinator at the Central State Farm, Hisar, Haryana, India.

country. About 200 on-farm trials with ICPL 366 were carried out in 15 districts of Nepal.

Elsewhere, in the dry zone of Sri Lanka at Maha Illupallama station, ICRISAT's short-duration pigeonpea lines have given good yields, ranging from 4 t/ha to 5.2 t/ha in two harvests made in 5 months.

Cooperative hybrid pigeonpea trials were sent to 10 locations in India, and parental material of ICRISAT hybrid ICPH 8 were given to four seed companies in India for seed production.

Several advanced ICRISAT pigeonpea lines with large white seeds and multiple disease resistance were identified for multilocational trials in Gujarat and Karnataka states in India.

A significant achievement for ICRISAT pigeonpea breeders this year was the development of high-yielding, large-podded, large-seeded dwarf pigeonpea plants in all three phenological groups, suitable for both vegetable and dry seed purposes.

While several ICRISAT/ICARDA chickpea varieties reached farmers in Algeria, Cyprus, Italy, Syria, and Tunisia, and one ICRISAT chickpea variety in Nepal during 1988, results in India were equally encouraging. Three wilt-resistant ICRISAT kabuli chickpea varieties and one wilt-

resistant ICRISAT desi chickpea variety gave better yields than local varieties in farmers' field trials in four Indian states. Many requests for seeds of these varieties were received.

In multilocational farmers' field trials in Nepal, ICRISAT's chickpea line ICCL 82108 produced 27% more grain than locally cultivated varieties.

Groundnut breeders at ICRISAT were also happy this year when the Central Sub-committee on Crop Standards, Notification, and Release of the Government of India cleared ICGS 44 (ICGV 87123) for postrainy-season cultivation in Gujarat state. This variety has become popular in all groundnut-growing areas of India because of its excellent performance in both the postrainy and rainy seasons.

A groundnut variety, Girnar 1 (CGC 4018), also released in India in 1988, is resistant to foliar diseases, and was developed by the Coordinating Groundnut Unit of the All India Coordinated Research Project on Oilseeds (AICORPO) from segregating populations supplied by ICRISAT.

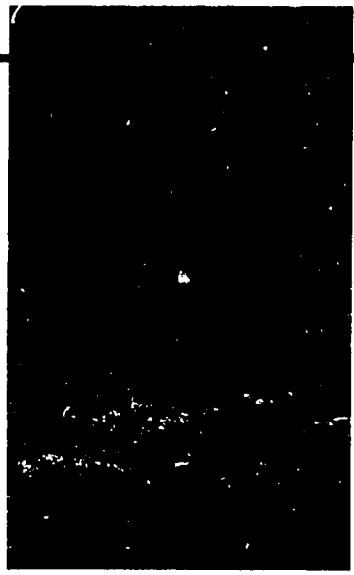
ICCV 2, a wilt-resistant, short-duration chickpea line growing alongside Rabat, a wilt-susceptible variety at ICRISAT Center.

The performance of the ICRISAT groundnut selections ICGS 37 and ICGS 6 may result in their release in some Indian states in the very near future.

In Pakistan, two ICRISAT groundnut varieties, ICGS 44 and ICGS 37, are in the process of registration by the National Seed Registration Department of Pakistan. ICRISAT groundnut selection ICGS 36 has been identified as ICRISAT's most promising variety for Nepal by the National Oilseeds Development Programme of Nepal. In Gabon, three ICRISAT varieties, after four seasons of regional evaluation, have been selected for national evaluation.

ICRISAT Materials That Reached Farmers in 1988

Crop	Release material	Region/country
Sorghum	ICSV 112 (SPV 475)	India (as CSV 13)
	ICSV 145	India (as SAR 1)
	INIAP 201	Ecuador
	AGROCONSA 1	El Salvador
Pearl millet	MP 124 (ICTP 8203)	Andhra Pradesh and Maharashtra states, India
Chickpea	ILC 482 (ICARDA)	Algeria
		Syria (as Ghab 1)
	ILC 3279 (ICARDA)	Algeria
		Cyprus (as Yilousa)
		Italy (as Sultano-for winter sowing)
		Syria (as Ghab 2)
		Tunisia
	ILC 464 (ICARDA)	Cyprus (as Kyrenia)
	ICCV 1 (ICCC 4)	Nepal (as Sita)
Pigeonpea	Quest (selected from an ICRISAT four-way cross)	Australia
	ICP 9145	Malawi
Groundnut	ICGS 44 (ICGV 87128)	Gujarat state, India
	Girnar 1 (developed from ICRISAT material)	India



Heavy leaf fall of 3-year-old perennial pigeonpea as seen here can have major benefits on soil fertility.

Insights on Better Resource Management of the Semi-Arid Tropics

ICRISAT's research on improved systems of resource management aims to attain balanced systems at relatively high productivity levels. ICRISAT scientists focus on improving farming systems in two important types of soil: Alfisols (red, loamy soils) and Vertisols (dark, clayey soils) in the medium-to-high rainfall zones (750 - 1000 mm per annum and above) in India, and for Entisols (sandy loam soils) and Alfisols of sandy texture in the low-to-medium rainfall zones (500 - 1000 mm per annum) in West Africa. Existing systems of resource use in representative villages of these regions are studied to enable us to understand the interrelationships of the harsh environment and the prevailing socioeconomic conditions.

ICRISAT scientists observe, measure, and analyze the resources of the semi-arid tropics: physical, biological, and institutional. These include soil, water, nutrients, cultivated varieties, and animal use. After investigation of the relevant components, packages and systems are assembled to overcome constraints to productivity. These are tested and then adopted. An example of this process of testing new technology developed by ICRISAT is the operational scale research (OPSCAR) project demonstrated at the ICRISAT Sahelian Center (see separate item on page 30) and now being adopted by several national research services in West Africa.

Studying the Soil

Crops growing on Indian Vertisols respond less to phosphorus fertilizer than crops growing on Indian Alfisols. This difference in response has been attributed to a large amount of phosphorus in the fertilizer being fixed by Vertisols, making it unavailable to the plant. However, scientists at ICRISAT found that all the adsorbed phosphorus remained exchangeable in both Vertisols and Alfisols.

ICRISAT scientists, in collaboration with the University of Reading in UK, measured the amounts of exchangeable, nonexchangeable, and total adsorbed phosphorus in each soil by equilibrating the soil samples. Adsorption and desorption were measured using the isotope ^{32}P to discriminate between phosphorus already in the soil and that added. The results of the experiment confirmed that Vertisols do adsorb more phosphorus than Alfisols. However, the scientists noted that greater sorption is not sufficient to explain the lack of response of crops to application of phosphorus fertilizer on Vertisols. The data showed that virtually all of the adsorbed phosphorus can be desorbed, so practically no phosphorus fertilizer is irreversibly fixed by the soil.

These results also support field work on the phosphorus response of sorghum in Vertisols, showing that phosphorus is more freely available than indicated by the chemical soil test.

In Niger, it is generally recommended that nitrogen fertilizer should be applied to sorghum in two equal doses for efficient uptake. The first dose is

applied 2 weeks after sowing and the second 6 weeks after sowing when crop growth becomes rapid.

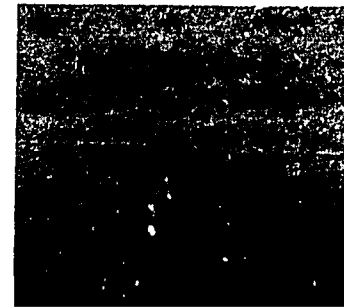
Studies by ICRISAT scientists using isotope ^{15}N indicate that the nutrient is poorly absorbed by the sorghum plant when it is small and the nutrient can be carried downwards by infiltrating water. However, when the second application is made, the roots are better developed and the uptake is more efficient. It was also noted that a third of the applied nitrogen from the fertilizer found its way to the plant, mostly in the grain. From this observation, it is evident that to assure good response to the fertilizer, it is necessary to split the application into two doses.

This year, ICRISAT scientists completed an intensive examination of indigenous systems of soil classification in three ICRISAT study villages of peninsular India. These classifications were drawn up solely from interviews with farmers and were based on their perceptions. Farmers in Vertisol areas viewed their soils as less distinct than farmers in the Alfisol region. These fundamental differences are reflected in variations in crop and soil-management practices between fields within a village.

Though major differences in farmers' systems of soil classification were evident between villages with red and black soils, laboratory analyses generally supported the farmers' thinking. The indigenous systems appear to provide an informative and compact base for indexing variation in land quality. The farmers' soil classification also appears to have the potential to hasten the process of technology generation and transfer. Whether the classification from a representative village can be used in a larger context is yet to be determined.

The red, loamy Alfisols have a strong tendency to form a surface seal following the impact of raindrops. This seal, coupled with an inherently small water-holding capacity, promotes runoff and erosion. When dry, this type of soil becomes hard and impedes seedling emergence, a bane of dryland farmers the world over.

Red, loamy Alfisols form a strong surface seal following impact of raindrops and this can impede seedling emergence.



*A bird's eye view (*below*) of experimental plots of Alfisols at ICRISAT Center with varying quantities of sand added to study differences in water infiltration and soil crust strength.*

ICRISAT Center scientists this year found that addition of coarse sand to surface soil can improve water infiltration and reduce soil strength, since the surface of such a soil reduces sealing and crusting. Soil surfaces so treated resisted detachment of soil by the impact of raindrops as the easily erodible material washed away.

Cropping Systems

If understanding of the mechanics of soil characteristics and soil nutrients is crucial to good productivity, so is the understanding of interaction between crops. In 1987, ICRISAT scientists began an experiment at Gwalior, India, to calibrate the residual effect of ICRISAT's short-duration pigeonpea genotype ICPL 151 on a subsequent wheat crop, following conflicting reports of the effects of pigeonpea on subsequent crops.

ICPL 151 is particularly suited to the short-duration pigeonpea-wheat rotation (wheat after pigeonpea) of northern India because of its high

Wheat growing on a plot that had grown ICRISAT's short-duration pigeonpea ICPL 151 previously, showed the equivalent effect of adding 40 kg of N fertilizer per hectare at Gwalior, Madhya Pradesh, India.

yields, short duration, and lesser crop height than varieties of similar crop duration.

Wheat grown on a field previously planted with ICPL 151 exhibited the effect of 40 kg of nitrogen per ha by both apparent biomass and foliage greenness. When compared with plots planted to pearl millet before wheat, the positive effect of growing pigeonpea before wheat was the equivalent of 30 kg of nitrogen per ha more than that of pearl millet. Therefore, it appears that ICPL 151 can appreciably improve the nitrogen nutrition of a following wheat crop. This is somewhat surprising because few nodules were detected on pigeonpea roots during growth and because of the short period between crops. A rapid breakdown and nitrogen release from decomposing pigeonpea debris is suggested by ICRISAT scientists.

In collaboration with the Directorate of Rice Research of the Indian Council of Agricultural Research (ICAR), ICRISAT scientists conducted experiments at ICRISAT Center to increase cropping intensity in rice-based systems by intercropping (where two crops grow side by side) and rotational cropping (where one crop follows another in the same field).

An ICRISAT scientist examining a sorghum-based cropping systems trial, within the Cómision Latinamericano de Investigadores en Sorgo (CLAIS) network, in El Salvador.

Instruments measure microclimates in alley cropping experiments at ICRISAT Center.

Earlier experiments in 1986 and 1987 indicated that the differences in the maturity dates of cultivated rice varieties had no effect on the yield of postrainy-season crops. However, a single irrigation application resulted in substantial increases in yields of sorghum, pigeonpea, and groundnut, though not of chickpea.

These findings suggest that short-duration cultivated varieties of pigeonpea, groundnut, and chickpea in rice fallows do not produce economic yields. A possible reason for the poor performance could be short daylengths during the postrainy season.

These experiments on rice-based cropping systems by ICRISAT scientists indicated that although long-duration legume varieties can produce high biomass accumulation, grain yield increase is only marginal without supplementary irrigation. Poor aeration and high compaction of soil probably restricted root penetration and also explain why the roots did not extract moisture stored in the soil profile at deeper layers.

Keeping Sustainability in Perspective

The concept of sustainability in agriculture is not solely a concern for the environment, but more a concern for creating a balance between human and livestock needs and preservation of the environment. Many of the cropping systems elucidated earlier, such as the effect of pigeonpea crop residue on wheat, contribute to sustainability.

The spin-off from fertilizer use in on-farm studies in Gobery, Niger, is a good example. ICRISAT scientists found pearl millet yield increased 2.5 times with the use of fertilizers under farmers' management there. The use of fertilizer improved both total dry matter and stand density. In other words, fertilizer helped early pearl millet crop development and survival.

A bird's eye view of an alley cropping experiment, using a two-way systematic design on a Vertic Inceptisol.

Moreover, fertilizer inputs led to an increased supply of stover to the farm, enabling sufficient amounts to be left on the soil surface at sowing time to provide protection from soil erosion. ICRISAT scientists believe that if this practice is adopted, it could be crucial in maintaining sustainability of crop production in the Sahel.

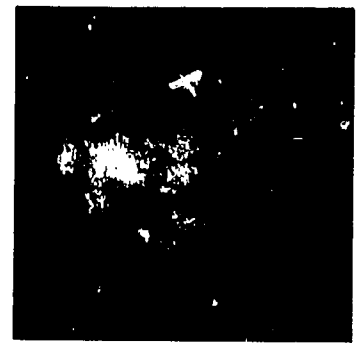
In the semi-arid tropics of India, trees compete strongly with crops for water. Crops do not have the positive interactions, such as increased crop yield and improved soil fertility, often observed in conventional intercropping elsewhere in the humid tropics.

ICRISAT scientists found alley cropping based on leucaena (*Leucaena leucocephala*) was not more productive than a sole leucaena crop, even when leucaena is not managed optimally.

ICRISAT studies indicate that application of more fertilizer to annual crops is economically preferable to sacrificing land to leucaena hedgerows. However, leucaena plants were effective in controlling seasonal runoff and erosion. At ICRISAT Center, it was noted that daily runoff and erosion decreased as the proportion of leucaena increased.

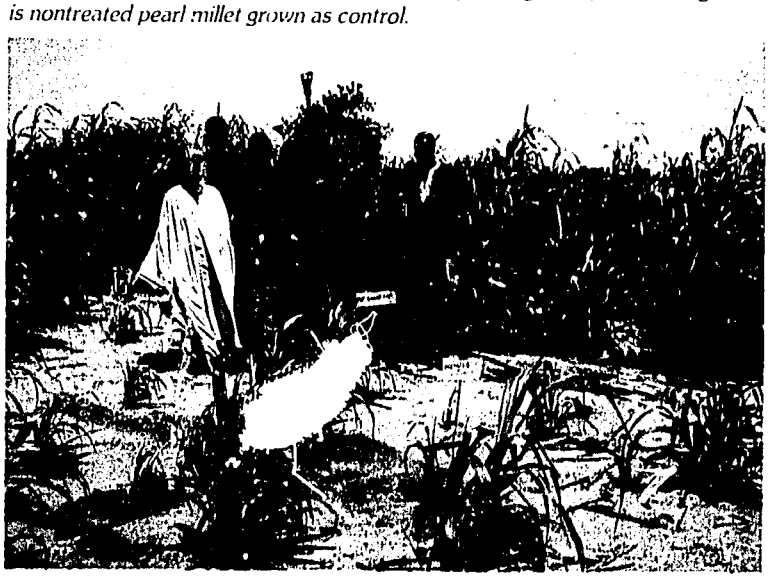
Studies on microclimates (climate in the shade of big plants) in alley cropping established that the amelioration of temperature is insignificant in the environment studied. This is because during summer, when the microclimate modification is most effective, it is too dry to sow understory crops.

Scientists at ICRISAT Center found this year that the economic superiority of leuceana-based alley cropping was small. It is successful where lack of rainfall is not a major constraint to crop yield; where inorganic fertilizer is inappropriate, unavailable, or too expensive; and where competition with annual crops is not appreciable. The physical and economic environments in the semi-arid tropics of India differ greatly from conditions elsewhere. The more important factors are the lack of substantial positive



*Fisheye photograph used to estimate canopy cover in an agroforestry system with castor bean (*foreground*) as an understory crop in a* Faidherbia albida *plantation, Hayatnagar, Andhra Pradesh, India.*

*Farmers and an ICRISAT/IFDC scientist (*extreme right*) in a farmers' field at Gobery, Niger, where use of phosphorus fertilizer under farmers' management increased pearl millet dry matter and stand density* (background). *In the foreground is nontreated pearl millet grown as control.*



interactions, such as mulching and crop growth, small environment improvement, and severe competition for moisture between leucaena and annual crops. ICRISAT's attention to agroforestry is now, therefore, concentrated on a nonaggressive species—perennial pigeonpea—which has many characteristics beneficial to intercropping systems.

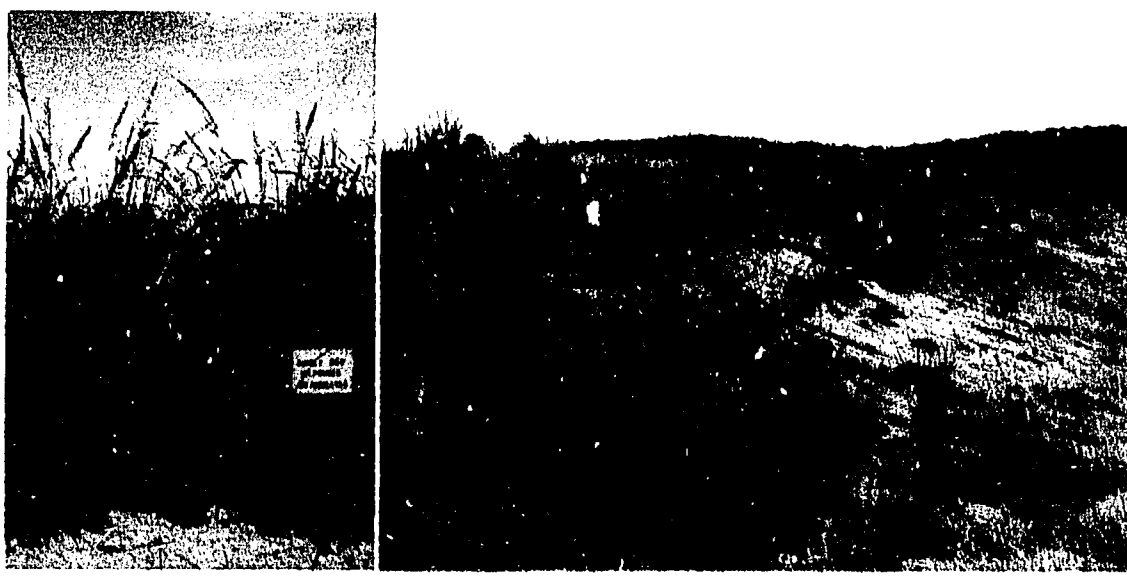
Since 1987, ICRISAT scientists have been studying the effect of vetiver grass (*Vetiveria zizanioides*) for soil and water conservation. These grasses are normally grown as hedges planted at intervals across slopes to reduce runoff velocity and soil erosion and to increase infiltration and sediment deposition within fields. The establishment of clumps of the grass proceeded satisfactorily. Experiments showed that a single-row hedge was preferable provided its effectiveness was not impaired by reduced width. The grass was found capable of surviving the dry summer months and the grass barrier of surviving frequent grazing (provided pruning is a reasonable simulation of grazing). ICRISAT scientists noted that two or three prunings were essential to minimize competition with crops, for height, moisture, and nutrients.

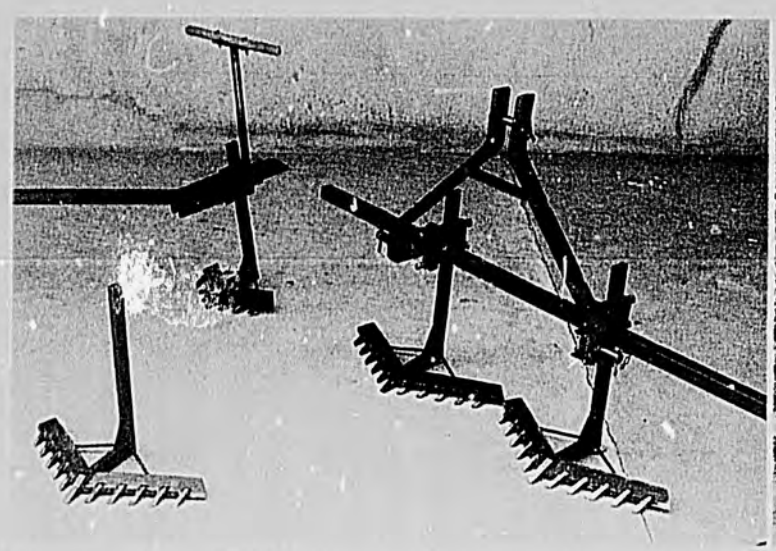
New Implements Developed

Most West African families own at least one donkey for pulling a cart. However, donkeys remain idle while the family engages in weeding and sowing operations. ICRISAT scientists designed a low-cost cultivation implement (partly at ICRISAT Center and partly at Cinzana, Mali) that can be pulled by a donkey. This implement can accomodate either a ridger or a set of three duckfoot sweeps.

This donkey-drawn tillage implement consists of a frame made of a wooden plank with two rigid beams. It can be hitched to a donkey with a

*Effects of vetiver grass on groundnut (*left*) and establishment studies on a row of vetiver grass on a slope (*right*) at ICRISAT Center.*



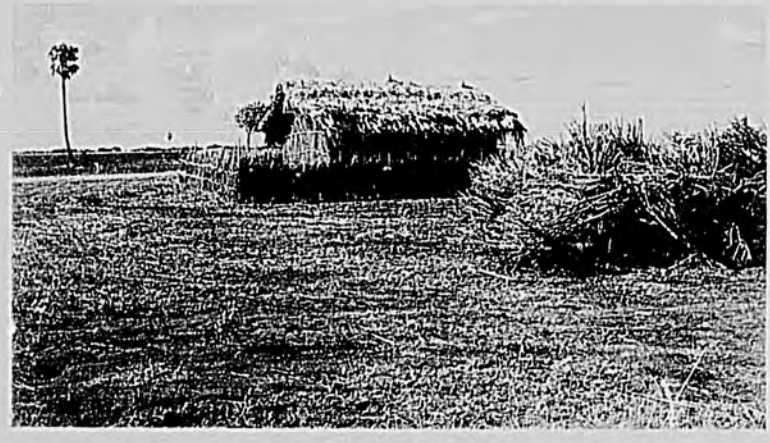


Harvesting with an ICRISAT-designed groundnut digger (right) and its attachments (left)

Harvest time and yield losses are less than 30 kg/ha in average and costing approximately US $75 or CFA 20,000. 0.8 ha can be filled with this implement in a single day.

ICRISAT scientists and engineers also designed and developed a groundnut digger that removes the tops of runners which grow the crop in hardpan. Which can dig and lift hard pan and the pines difficult, difficult plants or runners are interwoven. Existing implements are heavy-duty types and they are unable to penetrate to a stable depth. As a result, harvesting must take place on soil that has softened, the soil, and the delay increases losses and exposes the crop to the longer exposure of pests and diseases.

A simple digger for harvesting groundnuts, can be attached to a mouldboard or disc plough and pulled by a tractor. The digger remains at a set 100 mm in soil and. A simple digger bottom covers a 1.0 m strip of one row of the crop.



Groundnut harvesting in the main field, [illegible] with [illegible] Sports [illegible] Sponsor [illegible] 1988 at ICRISAT Center

Most West African families have at least one donkey to pull a cart as this one in Niger; use of animal traction for ridging and weeding was found useful in OPSCAR trials.

OPSCAR's Improved Technology for Semi-Arid Tropics of West Africa

Scientists at the ICRISAT Sahelian Center (ISC), in partnership with the Institut national de recherches agronomiques du Niger, and more recently with the Institut d'économie rurale of Mali, have been testing components and combinations of technologies that researchers hope will have a role in producing more stable and sustainable agriculture in the drier regions of West Africa. Here rainfall is low, variable, and undependable, whereas potential rates of evaporation are very rapid throughout the year. Poor soils, a harsh environment, and the poor socioeconomic conditions of farmers contribute to low agricultural productivity. This operational scale research (OPSCAR) project identified research components showing promising results over the period 1986–88.

One of these components is the pearl millet/cowpea intercropping system (where both crops grow in alternate rows in the same field), first demonstrated at ISC. This component is now being adopted by national research services in West Africa.

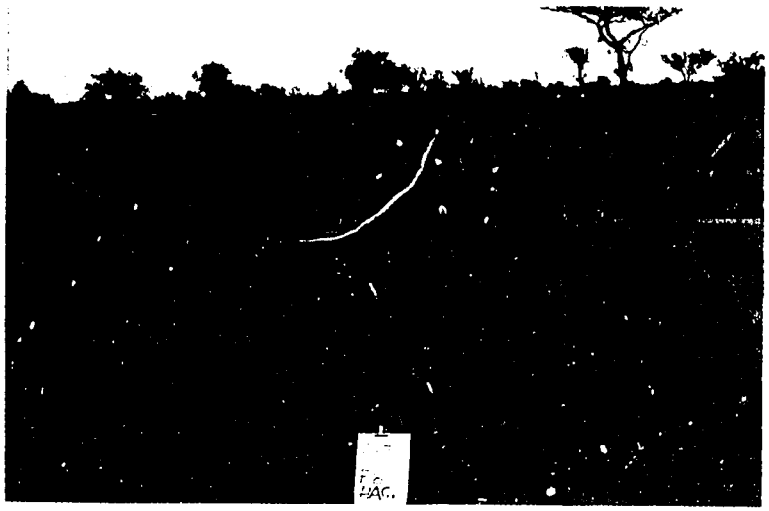
Another is the significant effect of ridging the field with animal traction and sowing on these ridged fields. The grain and stover yields of pearl millet in both sole crops and intercrops improved dramatically.

Ridging was found to have no significant effect on intercropped cowpea grain and hay, but resulted in a significant increase of sole-cropped cowpea yield.

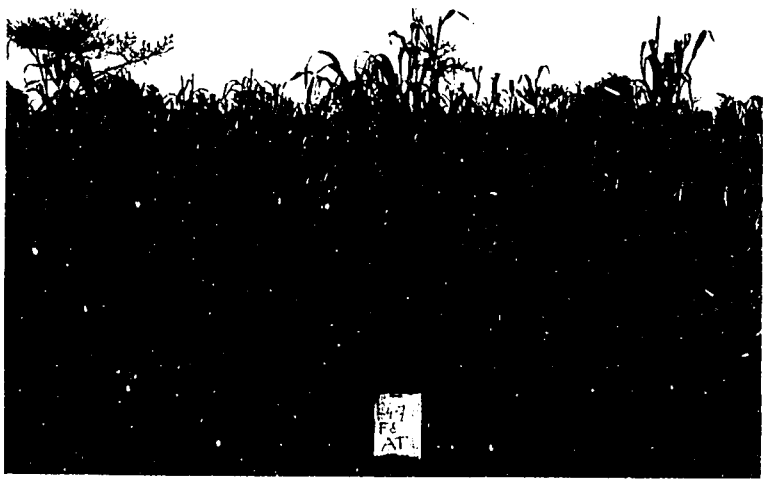
Yet another component is the dramatic advantage of the rotation system (where one crop is grown soon after another crop is harvested in the same field), vis-a-vis the continuous system. Pearl millet in 1988, after cowpea in 1987, yielded three times more grain than the continuous traditional system, and almost twice as much as the continuous improved system. Moreover, the production of stover doubled.

During the experiments, evidence was found indicating the advantage of a system combining limited application of phosphorus fertilizer (13 kg/ha), improved varieties of pearl millet, cereal-legume rotation, and the use of animal traction.

Better management increased production and productivity, as did the adoption of improved varieties. An improved variety of pearl millet, ICMV 5 (ITMV 8001), recommended for release to farmers in Niger, gave increased and stable yields. In cowpea, TVX 3236, an early-maturing, semierect type consistently outyielded other cultivars. Use of animal traction for ridging and weeding resulted in a significant reduction of labor.

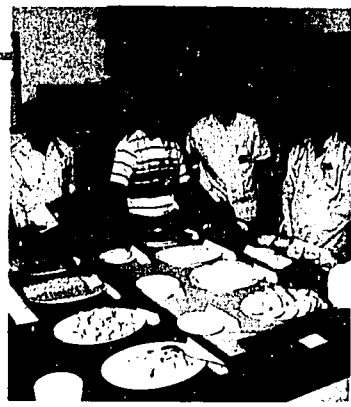


A pearl millet/cowpea intercrop cultivated manually after a similar intercrop in an OPSCAR trial.



A pearl millet/cowpea intercrop grown with help of animal traction, after a sole cowpea crop, in an OPSCAR trial.

Manually cultivated pearl millet/cowpea intercrop growing in an OPSCAR experiment plot that had grown cowpea previously.



Participants of the Sorghum Field Day visit the biochemistry laboratory at ICRISAT Center and view sorghum food preparations.

Transfer of Technology

An important part of ICRISAT's mandate is to assist in the development and transfer of technology to farmers through cooperation with national and regional research programs and by sponsoring workshops and conferences, operating training programs, and assisting extension activities. ICRISAT gave this mandate objective considerable emphasis during 1988.

Positive Impact of LEGOFTEN Coordinated Trials in India

The groundnut crop accounts for about 60% of India's total edible oil production. In recent years, however, the country's production has not met the growing demand, resulting in high annual foreign exchange expenditures on edible oil imports.

In 1987, the Government of India asked ICRISAT to help improve the country's groundnut production. ICRISAT organized a training workshop on technology transfer with participants from the Indian Government and the Departments of Agriculture of six groundnut-growing states to discuss basic and applied aspects of groundnut productivity.

Following this workshop, staff of the state Departments of Agriculture, in collaboration with ICRISAT, set up high-yield demonstrations in several Indian groundnut-growing states based on improved packages of practices that included ICRISAT-developed varieties. The Indian Government provided the funds for these demonstration trials, while ICRISAT provided the seeds. ICRISAT's Legumes On-farm Tests and Nursery (LEGOFTEN) Unit, consisting of a multidisciplinary team of scientists and

A prototype of the broadbed-and-furrow maker indigenously developed by farmers at Digras, Maharashtra, India, after noting the benefits of cultivating groundnut on broadbeds.

Groundnut growing on broadbed-and-furrow contours in a farmer's field at Digras, Maharashtra, India.

Effects of growing groundnut on broadbed and furrows on root development and pod formation (right) *and when grown on flat bed* (left) *on the same variety in adjacent plots at Amraoti, Maharashtra, India.*

trained field staff, coordinated and monitored the trials conducted by the state Departments of Agriculture. Successful groundnut trials gave yields between 2.28 t/ha (at Musaravakkam, Tamil Nadu) and 5.26 t/ha (at Basmat, Maharashtra). At nine locations, the yield ranged between 3.5 t/ha and 4.8 t/ha. Traditional groundnut varieties also responded to improved management; at five locations these yielded more than 3 t/ha, the highest being 3.57 t/ha for variety TMV 2. Improved methods led to higher shelling percentages, seed weight, and oil content.

Vice Chancellor of Marathwada Agricultural University (with cap) *visits LEGOFTEN's extra-early pigeonpea trials at Brahmangaon, Maharashtra, India.*

ICRISAT's pigeonpea line ICPL 85014 growing in a LEGOFTEN coordinated trial at Danishpet, Tamil Nadu, India.

LEGOFTEN scientists studied the yield constraints in farmers' fields, including water distribution, diseases, and nutrient deficiency. Gypsum application, they noted, resulted in improved pod filling. The raised bed-and-furrow system induced good root development, good nodulation, better crop growth, better pod filling, and early maturity.

During the 1987 rainy season, in two groundnut-growing states of India, Maharashtra and Karnataka, farmers adopted improved cultivation methods on only about 9 ha. In the 1988/89 postrainy season, the improved method will be partially or fully used on more than 70 000 ha in the two states. These figures show the dramatic impact of the trials.

ICRISAT extended this approach to its other mandate legume crops—pigeonpea and chickpea—at the request of India's Ministry of Agriculture. ICRISAT's pigeonpea line ICPL 87 performed well in southern India where an insect pest called the pod borer (*Helicoverpa armigera*) was controlled. This pigeonpea line is being grown on about 10 000 ha in Maharashtra and has been planted on about 4 000 ha in Madhya Pradesh. The popularity of ICPL 87 in Maharashtra resulted from four farmers achieving yields of 4.0–4.5 t/ha with this variety. Another ICRISAT-released pigeonpea line, ICPI 151, is currently being tested in northern India in LEGOFTEN trials.

In LEGOFTEN on-farm trials, chickpeas gave encouraging results, ranging from 1.6 t/ha to 3.4 t/ha. Of these varieties, ICRISAT variety ICCC 32 proved superior to local ones.

Developing Human Resources

During the year, 224 research scientists and technical staff from 51 countries participated in individualized training programs. These persons were nominated by national ministries of agriculture, universities, or semi-arid tropical research and development programs. Such activities bolster research capabilities in the countries that the participants represent

MSc research scholar from Tanzania studying an agronomy experiment at ICRISAT Center.

through their active role in evolving and using improved technologies.

International, regional, and national training activities conducted by ICRISAT scientists and staff involved more than 216 national scientists, technicians, and students from 32 countries. Training courses at ICRISAT Center and at regional research centers dealt with research-skill development, research-station management, thesis research, field study, field days, and traveling seminars.

Major specialized events aimed at improving special skills. One such course was on the detection of groundnut viruses, with special emphasis on peanut stripe virus. This course, held in Indonesia, was attended by 12 participants from 10 Asian nations.

PhD student observes groundnut's physical growth characteristics.

Participants of a training course for Nepalese subject matter specialists visit chickpea plots at Nepalgunj, Nepal

Another such event was the course on integrated control of grain legume pests in Asia conducted at ICRISAT Center which benefited 10 agriculturists from nine countries. Two specialized courses were arranged on the evaluation of grain and food quality of ICRISAT mandate crops; one on cereals which assisted seven African participants and another on legumes which trained eight Asian participants.

ICRISAT's Asian Grain Legumes Network (AGLN) organized its first in country training course on legume production in Nepal. It was attended by 18 subject matter specialists from their district offices and farming systems research development divisions.

Networks Strengthened

ICRISAT strengthened its links with scientists in national agricultural research systems (NARSs) through its several international nurseries, workshops, training activities, and literature distribution. These links

Participants of a peanut stripe virus detection course visit a screening trial in Indonesia (inset: symptoms of peanut stripe virus on groundnut leaves).

assure that ICRISAT developed material and technology is communicated to NARS scientists, and facilitate feedback from them to ICRISAT.

ICRISAT signed bilateral Memoranda of Understanding with the People's Republic of China and Bangladesh and a Memorandum of Agreement with Indonesia. These ties will help ICRISAT's AGLN improve the process of technology transfer in these countries. For instance, AGLN scientists utilizing existing agreements with Nepal, Burma, and Sri Lanka attended bilateral meetings with national agricultural scientists working on legumes in these countries during 1988, re-examining each country's individual problems and research priorities.

A direct outcome of such linkages was the Workshop on Agroclimatology of Asian Grain Legume Areas held at ICRISAT Center, which brought together legume scientists and agroclimatologists from nine Asian countries. Each participant brought production and climatology data from his/her country. The data were used to develop maps showing present distribution of groundnut, chickpea, and pigeonpea, the extent of constraints to production; and potential areas for production of these crops as determined by the agroecological patterns in each country. The text and

Groundnut growing in a farmer's field in Burma, a member-country of ICRISAT's Asian Grain Legumes Network.

Harvested pigeonpea stalks being carted in for threshing in Burma.

Groundnut growing in a farmer's field in Indonesia, which formally joined the Asian Grain Legumes Network in 1988.

maps will provide readily understood information to help policymakers, research planners, and legume scientists develop their plans.

In 1988, AGLN evolved beyond the bilateral stage when scientists from national, regional, and international research organizations met in Indonesia to suggest ways to improve groundnut production in the Asian region. Priorities for research were identified, and recommendations made for continued research collaboration and increased training of scientists within the region.

Indonesian and Thai participants exchange information and ideas at the Workshop on Agroclimatology of Asian Grain Legumes.

Events Promoting Technology Transfer

Several workshops, meetings, and conferences were held at international, regional, and national levels all over the world.

One such event was a highly successful international workshop on the uses of sorghum and millets held at Bulawayo, Zimbabwe, as part of ICRISAT's efforts at evolving a global strategy in food production. It was attended by over 50 participants from five continents.

Another event that augmented ICRISAT's research efforts was a sorghum Field Day organized exclusively for Indian seed producers at ICRISAT Center. After visiting the fields, the representatives of 20 seed companies held discussions with ICRISAT scientists on problems of seed production, production areas, and sowing dates. A similar event, called the Visitors' Day, was held at ICRISAT Center for pearl millet seed producers.

Field day participants visit a sorghum field at ICRISAT Center.

Cooperative Research

Technology transfer also occurs through cooperation with national programs. The large-scale screening technique for resistance to sorghum downy mildew (*Peronosclerspora sorghi*), developed and used by ICRISAT staff at Dharwad, India, since 1981 was succesfully established at Golden Valley, Zambia, for the Zambian national program. Of the 2830 sorghum lines screened, 733 were identified as resistant to downy mildew.

ICRISAT initiated a cooperative project with Rajasthan Agricultural University on pearl millet improvement at Fatehpur, India. This location should greatly improve ICRISAT's ability to breed material adapted to arid regions in India. A successful pearl millet variety in this arid zone must be adaptable to drought, high soil temperatures at emergence, and high air temperatures during the grain-filling stage. Further requirements are good fodder yield, and possibly, fodder quality. Assuming that this complex combination of traits would most likely be found among local landrace material, ICRISAT scientists evaluated many landrace populations from Rajasthan. The results confirm that these are good parent materials for starting a varietal improvement program targeted for this region. However, genes for downy mildew resistance may have to be introduced into these landraces, which are quite susceptible to this disease.

A Zimbabwean farmer holds various forms of pearl millet heads grown in his field.

Germplasm Collection Successes

Variability and pote ality of the world's genetic resources provide the basic raw material for crop improvement research. Over the past 15 years, ICRISAT botanists have diligently collected, assembled, evaluated, documented, and conserved a vast collection of germplasm accessions of sorghum, pearl millet, chickpea, pigeonpea, groundnut, and minor millets. These are utilized by ICRISAT scientists in crop improvement and are freely available to scientists working on these crops all over the world.

In 1988, ICRISAT's untiring efforts at collection of germplasm material added 2096 accessions of ICRISAT mandate crops plus 153 of minor millets to the gene bank, raising the total to 96 200.

During the year, 19 248 seed samples were distributed to ICRISAT scientists, 38 407 to scientists in India, and 20 410 to scientists elsewhere to help in their research.

A sorghum germplasm collection mission was carried out in northern Cameroon in collaboration with the Institute of Agronomic Research, Ministry of Higher Education and Scientific Research, Cameroon. The mission successfully collected 250 samples of transplanted (Muskwari) sorghums.

Another mission was undertaken in 1988 in Zimbabwe in collaboration with the SADCC/ICRISAT Sorghum and Millets Improvement Program.

Transplanted (Muskwari) sorghum germplasm being collected in northern Cameroon.

Chickpea landrace samples being collected in Syria.

This mission succeeded in collecting 1208 samples of sorghum, pearl millet, groundnut, and other crops.

In collaboration with ICRISAT's AGLN and Nepal's National Oilseeds Development Project, 14 groundnut germplasm samples were collected by ICRISAT staff from the midhills region of that country.

A multicrop expedition sent to Syria in collaboration with Syria's Ministry of Agriculture, and the International Center for Agricultural Research in the Dry Areas collected 85 samples of cultivated chickpea and 5 samples of its wild relatives.

In India, in collaboration with the National Bureau of Plant Genetic Resources (NBPGR), six collection missions were launched in the states of Andhra Pradesh, Gujarat, Haryana, Madhya Pradesh, and Tamil Nadu. These missions collected 119 samples of sorghum, 388 of pearl millet, 51 of chickpea, 86 of groundnut, and 74 of minor millets.

Evaluation of germplasm in different locations is important in studying the resources. Towards this end, multilocational evaluations were carried out in collaboration with NBPGR at Issapur, Akola, Jodhpur, and Jorhat, where 2993 accessions of sorghum, 2581 of pearl millet, 1320 of chickpea, 850 of pigeonpea, and 1500 of groundnut were evaluated.

In a collaborative effort between the Somalian Ministry of Agriculture and ICRISAT, the entire Somalian collection was evaluated at Baidoa, Somalia. Twenty-nine most promising landraces were selected. In addition, 2000 accessions of early-maturing germplasm from the world collection at ICRISAT Center were evaluated. Of these, 69 accessions were selected based on earliness, agronomic eliteness for grain and fodder, and grain quality. These will be further tested and utilized in the Somalian breeding program.

An ICRISAT research associate (right) collects groundnut from a farmer's stored harvest in Madhya Pradesh, India, during a joint collection mission with NBPGR.

Continued evaluation of pigeonpea germplasm in Kenya helped the national program identify at least four promising lines that are now being multiplied for release as vegetable-type varieties.

At Debre Zeit, Ethiopia, 1034 chickpea accessions were evaluated.

This year, ICRISAT, with the help of its Genetic Resources Unit scientists, published the pigeonpea and chickpea germplasm catalogs containing evaluation data and passport information of its entire germplasm collection of the two crops. These catalogs are expected to be of considerable help to scientists working on improvement of these two crops throughout the world.

A workshop on collaborative germplasm exploration and evaluation in India discussed the use of ICRISAT germplasm and its impact on crop improvement. Recommendations for future collaborative efforts in germplasm collection, evaluation, and utilization were finalized.

Somalian sorghum germplasm being evaluated at Baidoa, Somalia, in collaboration with ICRISAT.

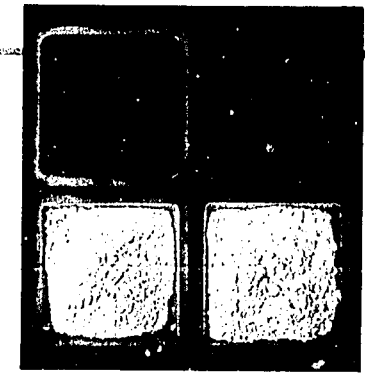
Studies on the End Products

Consumer acceptance, nutritive value, and utilization of cereals and legumes are important factors for breeders to consider. All their efforts could be wasted if they ignore these factors which indicate the directions to take to improve crops through selection for desirable traits (in addition to high yield, and resistance to drought, diseases, and insects).

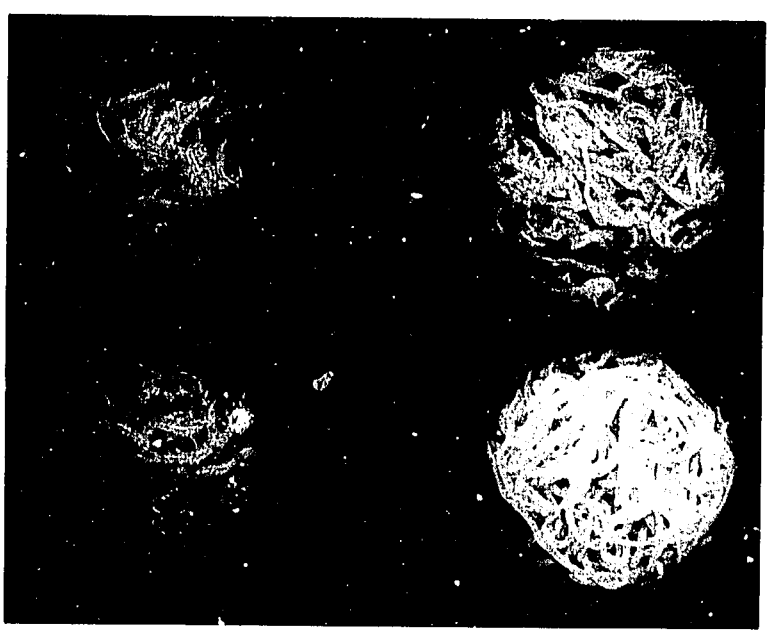
Studies were conducted on the viscosity of starch, a principal constituent of the chickpea grain. Starch in the kabuli-type chickpea was found to be more viscous than that of the desi types. This observation could be of practical importance in studies on the differences of the food-product quality of both chickpea types. Rat feeding experiments in the biochemistry laboratory at ICRISAT Center also established that kabuli chickpea contained more utilizable protein than desi chickpea.

In India, calcium and iron are reportedly deficient in the diets of low-income people, particularly infants, preschool children, and pregnant and lactating women. ICRISAT scientists found that these nutritionally important minerals are located in the outer layers of chickpea cotyledons, and can be lost during dehulling.

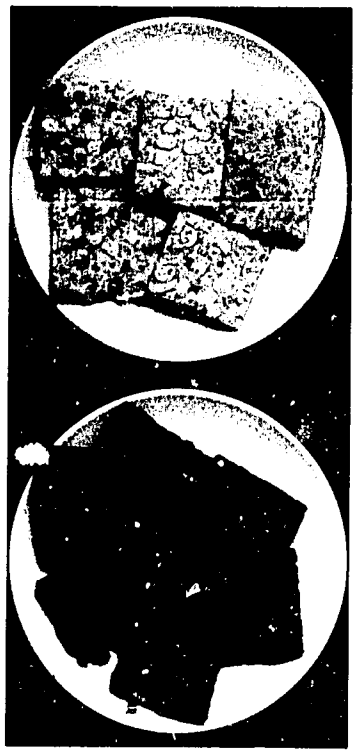
Examining new food uses of ICRISAT crops is also important to ICRISAT biochemists. They examined, in 1988, the utilization of pigeonpea in several Southeast Asian countries. Traditionally, mung bean starch is used for noodle preparation in Thailand. Results of experiments, conducted in collaboration with a trainee from Thailand, at ICRISAT Center, indicated that pigeonpea starch may be a good substitute for mung bean starch in noodle preparation in that country. The starch isolated from whole-seed pigeonpea produced noodles of poor to fair quality, whereas starch from pigeonpea dhal produced noodles of better quality than that of mung bean in terms of color, texture, clarity, appearance, and acceptance.



Differences in pakodas (top), *a popular snack food in South Asia made from desi and kabuli chickpeas and in flours* (bottom) *of both chickpeas. The desi chickpea products are at left, the kabuli products at right.*



Noodles prepared from pigeonpea (whole seed, top right; *dhal,* bottom right) *could substitute those made from mung bean (whole seed,* top left; *dhal,* bottom left) *in Thailand.*



Pigeonpea could partially substitute soybean in tempeh, *a popular preparation in Indonesia; at the top is raw* tempeh, *and below is fried* tempeh *made from pigeonpea.*

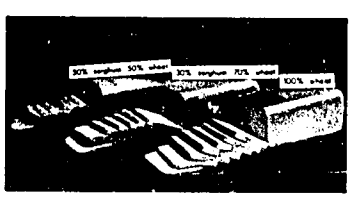
ICRISAT biochemists also developed a method for preparing *tempeh* (a fermented product) with pigeonpea, and compared it with soybean *tempeh*. The products were similar in taste, color, texture, and flavor. The results suggested that pigeonpea can be substituted for soybean in this popular food product in Indonesia. Preliminary studies also indicated that pigeonpea genotype C 11 (with brown seed coat) required more time to ferment than variety Nylon (with white seed coat).

Rat feeding trials on pigeonpea indicated that high-protein pigeonpea genotypes, developed at ICRISAT, contained more utilizable protein than those of other genotypes and are therefore nutritionally superior.

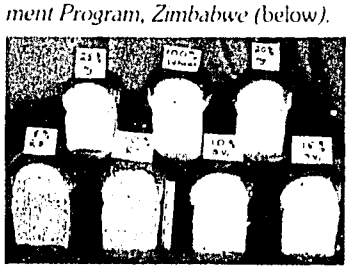
The stability of groundnut oil is mainly determined by the fatty acid composition of oil and the distribution of oleic (O) and linoleic (L) acids in the oil. The higher the O/L ratio, the more stable the oil in terms of keeping quality, and the less likely to become rancid. The fatty acid composition and the O/L ratios in 251 confectionery groundnut samples were determined. The ratios ranged from 0.78 to 2.74 with a mean of 1.47. (In the UK, the acceptable O/L ratio for buyers is 1.6.). These studies help breeders to determine whether a particular variety or line is worth improving or has a desirable trait that can be incorporated elsewhere.

The Bulawayo (Zimbabwe) workshop mentioned earlier attended by 50 participants from five continents had discussed the present and potential uses of sorghum and millet flours in combination with flour from maize, wheat, and legumes to make traditional foods, baked products, and specialty foods such as snacks and weaning food. The importance of sorghum and millets as animal feed was recognized, as were exploratory uses of sorghum and millet cellulose to make paper and building board, and sweet stem sorghum for the production of alcohol. The workshop, therefore, provided direction for ICRISAT's evolving strategy in food production and diversification of crop utilization.

ICRISAT biochemists also work in close cooperation with scientists in food research institutes in Ethiopia, Kenya, and Sudan. The usefulness of dehulling sorghum in improving the quality of the traditional food *injera* was demonstrated during the year.



Bread baked from wheat and sorghum flour combinations at ICRISAT Center (above) and SADCC ICRISAT Sorghum and Millets Improvement Program, Zimbabwe (below).



African trainees learn evaluation of grain and food quality of cereals at ICRISAT Center.

Other Research Areas

Chlorosis due to iron deficiency in groundnuts.

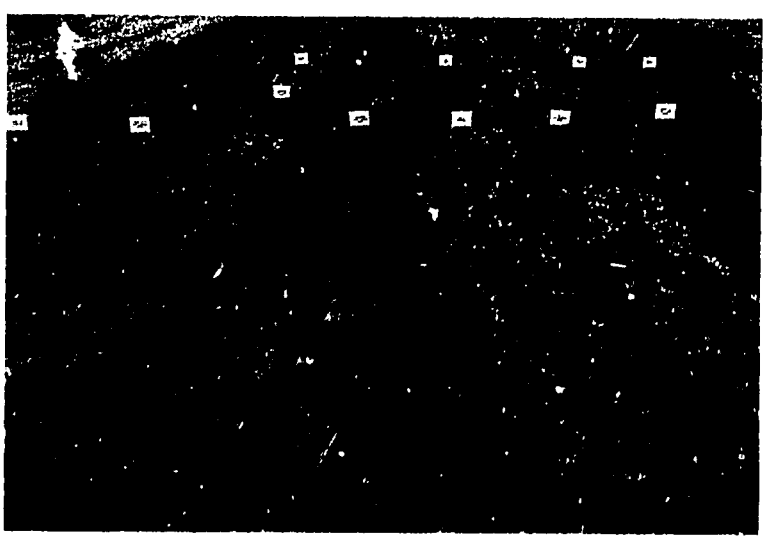
Genotypic differences in iron sensitivity were observed in groundnuts by ICRISAT scientists this year. In a miniplot experiment, different levels of sulfuric acid were applied to modify the pH value, which represents the acidity or alkalinity of soil. From an initial value of 8.3, lower values of pH were achieved in the surface layer of the soil by adding acid. Detailed soil samples were then taken to quantify changes in iron availability and overall nutrient status. A cultivated variety of groundnut prone to iron deficiency chlorosis was planted to study the expression of chlorosis under different pH levels.

By regular foliar feeding of iron compounds, ICRISAT scientists were able to correct chlorosis to a large extent. In the miniplot experiment aimed at correcting soil pH, it was found that chlorosis-susceptible genotypes showed very little chlorosis when grown in acid-treated plots.

A 380-page report was completed concerning the three agroecological zones of West Africa. It covered crop diversification, costs and returns of crop enterprise, the time consuming nature of hand-sowing methods, animal traction and sowing date interactions, women's role in crop management, labor use, soil fertility management, and profitability of different crop enterprises. The report contains information on costs and returns by crop enterprise on the gender of the decisionmaker, on location of the plot in relation to topography and the dwelling place of the inhabitants, on timing of the operations, on cultural practices, and on soil fertility management.

Long-term records of daily rainfall for 150 stations in Burkina Faso, Mali, and Niger were analyzed during the year for length of dry spells, their frequencies, and probabilities.

In collaboration with Rutgers University, USA, a survey was conducted in 1987 on coarse cereal research in the private sector in India to identify factors contributing to modest but vigorous private research on breeding these crops. The survey revealed that these seed firms spent 4% of their



A view of chlorosis affected groundnut plants.

seed sales on research. This compares well with the USA, where the seed industry spends about 3% of their seed sales on research and development. Pearl millet, sunflower, and sorghum received the most expenditure by these firms. The study found that the firms specialize in applied breeding research.

Chickpea being harvested at Gwalior, India.

The survey suggested that the public sector should shift emphasis to basic breeding or to biotechnology, and encourage close collaboration with the private sector. Private companies can undertake greater responsibility for seed production, the survey notes, while government seed corporations can reduce their production of hybrid seeds. However, the study suggested that production of certain hybrids by the public sector is probably the best strategy to ensure competition in the seed industry.

Higher man:land ratios probably result in greater urban demand for milk (and consequently fodder) for which modern cultivated varieties emphasizing grain qualities are often ill-suited for changing needs. ICRISAT economists suggested after in-depth analyses that investing more resources on infrastructural improvement will not have a marked effect on raising adoption ceilings. Faster adoption in laggard districts of India requires qualitatively different genotypes and more decentralized breeding, focusing on specific yield reducers and end-use preferences.

Scientists at the ICRISAT Sahelian Center, Niger, found that soil treatment with a mixture of carbofuran (an insecticide) and farmyard manure was very effective in reducing variation in crop growth (rainfed and irrigated) and increasing the yield of groundnut. The treatment also indicated positive residual effects and reduced populations of plant-parasitic nematodes.

Winnowing of chickpea grown at LEGOFTEN coordinated trials at Hathrol, Gujarat, India.

ICRISAT Governing Board—1988

Mr F. V. MacHardy, Chairman
7817 Saskatchewan Drive
Edmonton, Alberta
Canada T6G 2L3.

Dr N. S. Randhawa, Vice Chairman
Director General, Indian Council of Agricultural Research (ICAR) and Secretary to the Government of India
Department of Agricultural Research and Education
Krishi Bhavan, New Delhi 110 001
India

Dr L. D. Swindale, Ex-Officio Member
Director General, ICRISAT
Patancheru
Andhra Pradesh 502 324, India

Mr C. Srinivasa Sastry
Secretary to the Government of India
Ministry of Agriculture
Krishi Bhavan
New Delhi 110 001, India

Mr Shravan Kumar (until Jul)
Chief Secretary to the Government of Andhra Pradesh
Secretariat
Hyderabad 500 022, India

Mr G. R. Nair (from Aug)
Chief Secretary to the Government of Andhra Pradesh
Secretariat
Hyderabad 500 022, India

Dr P. L. Adkisson
Chancellor
Texas A & M University System
College Station
Texas 77843, USA

Mr M Birrell (from Nov)
8 Herbert Street
Medindie
South Australia 5081, Australia

Dr L. Brader
Director
Plant Production and Protection Division
Food and Agriculture Organization of the UN
Via delle Terme di Caracalla
00100 Rome, Italy

Dr C. Charreau
Director, IRAT
Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)
45 bis Avenue de la Belle Gabrielle
94130 Nogent-sur-Marne, France

Dr N. L. Innes (until Mar)
Deputy Director
Scottish Crop Research Institute
Invergowrie, Dundee, Scotland

Dr K. Kumazawa
Professor of Plant Nutrition and Fertilizer
Faculty of Agriculture
University of Tokyo
Bunkyo-ku, Tokyo, Japan

Dr W. T. Mashler
4 Woody Lane
Larchmont, New York 10538, USA

Dr J. Moncada de la Fuente
Presidente
Colegio de Ingenieros Agronomos de Mexico, A.C.
Sindicalismo 92, Mexico 18, D.F.

Dr B. K. Patel
Chief Agricultural Research Officer
Department of Agriculture
Mount Makulu Research Station
PO Box 7
Chilanga, Republic of Zambia

Dr P. M. A. Tigerstedt
Department of Plant Breeding
University of Helsinki
00710 Helsinki, Finland

Dr M. F. Traore (from Apr)
Conseiller Technique
Ministère de l'Agriculture
BP 2082
Bamako, République du Mali

ICRISAT Senior Staff— as of 31 December, 1988

ICRISAT Center

Administration

L.D.Swindale, Director General
J.S.Kanwar, Deputy Director General (until Mar)
M.Goon, Assistant Director General (Administration)
K.B.Srinivasan, Assistant Director General (Liaison)
B.C.G.Gunasekera, Advisor to Director General for Donor Relations
S.J.Phillips, Special Assistant to Director General for Educational Affairs (until May)
P.Reavey, Special Assistant to Director General for Educational Affairs (from Nov)
V.Balasubramanian, Sr Executive Officer (Director General's Office)
Joyce Gay, Sr Adm Secretary to DG
Surendra Mohan, Sr Adm Officer, Office of the DDG (until Dec)
P.Subrahmanyam, Sr Adm Officer, Office of the DDG (from Dec)
K.Sampath Kumar, Adm Secretary, Office of the DDG
P.Rama Murthy, Adm Officer, Office of Advisor to DG for Donor Relations (from Feb)
C.Geetha, Adm Secretary, Office of the ADG (Admn)
P.Sosamma Nair, Adm Officer, Office of the ADG (Liaison)
D.Mitra, Fiscal Manager
A.Banerji, Assistant Manager (Fiscal) (on special leave from Nov)
V.S.Swaminathan, Sr Accounts Officer
A.N.Venkataswamy, Sr Accounts Officer (until Dec)
C.P.Rajagopalan, Accounts Officer
P.A.V.N.Kumud Nath, Accounts Officer
K.Narayana Murthy, Accounts Officer
B.K.Vasu, Accounts Officer
T.Kulashekhar, Accounts Officer
T.K.Srinivasan, Accounts Officer
N.V.V.Rao, Accounts Officer (from Nov)
B.K.Johri, Personnel Manager (until Nov)
P.M.Menon, Personnel Manager (Acting)
N.S.L.Kumar, Sr Personnel Officer
P.Suryanarayana, Sr Personnel Officer
A.Hameed, Personnel Officer (until Dec)
A.J.Rama Rao, Adm Secretary (Personnel)
R.Vaidyanathan, Purchase and Stores Manager
C.R.Krishnan, Asst Manager (Purchase and Stores)
K.P.Nair, Sr Purchase Officer
D.K.Mehta, Sr Stores Officer
D.V.Rama Raju, Sr Purchase Officer
K.C.Saxena, Sr Stores Officer
K.R.Natarajan, Shipping and Purchase Officer
J.Banji, Purchase Officer (on secondment to ISC from Jan)
T.Gopalakrishnan, Purchase Officer
A.Lakshminarayana, Sr Scientific Liaison Officer (Visitors' Services)
Harish Sethi, Scientific Liaison Officer
Georgina Fredericks, Adm Officer (Visitors' Services)
K.K.Sood, Sr Security Officer
A.Ekbote, Security Officer (until Mar)
K.K.Vij, Asst Manager (Admn)(Delhi Office)
K.Santhanam, Manager (Internal Audit) (on contract from Feb)
N.Surya Prakash Rao, Sr Resident Medical Officer
K.Jagannadham, Transport Officer
A.Rama Murthy, Travel Officer
V.V.Ramana Rao, Adm Officer
V.Satish Kumar, Audit Officer (from Dec)

Research Programs

Cereals

Program Office

J.M.J. de Wet, Program Director, Cereals
K.Santhanam, Asst Manager (Adm) (until Jan)
S.Krishnan, Asst Manager (Adm)

Sorghum Group

S.Z.Mukuru, Principal Plant Breeder (until Jun)
L.K.Mughogho, Principal Plant Pathologist
J.M.Peacock, Principal Plant Physiologist (on sabbatical until May)
K.F.Nwanze, Principal Cereals Entomologist
C.M.Pattanayak, Coordinator CCRN (from Aug)
R.Stumpo, Asst Principal Plant Physiologist
B.L Agrawal, Plant Breeder
Belum V.S.Reddy, Plant Breeder
P.K.Vaidya, Plant Breeder
N.Seetharama, Plant Physiologist
P.Soman, Plant Physiologist
Suresh Pande, Plant Pathologist
R.Bandyopadhyay, Plant Pathologist
S.L.Taneja, Entomologist
H.C.Sharma, Entomologist
H.D.Patil, Sr Research Associate
K.David Nicodemus, Sr Research Associate
D.J.Flower, International Intern (until Jan)
C.S.Busso, Postdoctoral Fellow (from Jun)
H.Kokubu, Postdoctoral Fellow
M.A.Osman, Postdoctoral Fellow (from Feb)
S.O.K.Trichur, Research Scholar (until Aug)
K.G.Kausalya, Research Scholar (from Nov)
Mohd Hassan Aden, Research Scholar (from Aug)
Hassan A. Hassan, Research Scholar (from Aug)

Pearl Millet Group

F.R.Bidinger, Principal Plant Physiologist
S.B.King, Principal Plant Pathologist
J.R.Witcombe, Principal Plant Breeder
C.T.Hash, Associate Principal Plant Breeder (until Jun)
K.N.Rai Plant Breeder
B.S.Talukdar, Plant Breeder
Pheru Singh, Plant Breeder (until Jul)
S.B.Chavan, Plant Breeder
G.Alagarswamy, Plant Physiologist
V.Mahalakshmi, Plant Physiologist
S.D.Singh, Plant Pathologist
R.P.Thakur, Plant Pathologist
K.R.Krishna, Microbiologist
B.P.Reddy, Sr Research Associate
M.Peterschmitt, Postdoctoral Fellow (from May)
E.Weltzien, Postdoctoral Fellow (from Nov)

Kenya

V.Y.Guiragossian, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern Africa
S.Z.Mukuru, Principal Sorghum Breeder (from Jul)

Mexico

C.L.Paul, Team Leader and Principal Sorghum Agronomist (on sabbatical from Oct)
C.T.Hash, Principal Sorghum Breeder (from Jul)
R.Clara, Scientist, Sorghum Breeder

Legumes

Program Office

Y.L.Nene, Program Director, Legumes
D.G.Faris, Principal Coordinator, Asian Grain Legumes Network (on sabbatical until Sep)
C.L.L.Gowda, Acting Coordinator (until Oct) and Legume Breeder, AGLN
D.M.Pawar, Sr Agricultural Officer (Cooperative Trials, LEGOFTEN)
Sheila Vijay Kumar Sr Research Associate (from Mar)
P.Rama Murthy, Adm Officer (until Jan)
G.J.Michael, Adm Officer

Pulses Group

C.Johansen, Principal Agronomist
H.A.van Rheenen, Principal Plant Breeder, Chickpea
Laxman Singh, Principal Plant Breeder, Pigeonpea
A.B.S.King, Principal Entomologist, ICRISAT/ODNRI (until May)
M.Pimbert, Principal Entomologist (from Jul)
J.Arihara, Associate Principal Physiologist
N.Ae, Associate Principal Microbiologist
K.Okada, Asst Principal Microbiologist
H.J.Hansen, Asst Principal Plant Pathologist, ICRISAT/DANIDA (until Jun)
K.C.Jain, Plant Breeder, LEGOFTEN
Onkar Singh, Plant Breeder, Chickpea
M.P.Srivastava, Sr Plant Breeder (on contract from Aug)
K.B.Saxena, Plant Breeder, Pigeonpea
V.K.Sehgal, Sr Scientist (Entomology) (on contract from Feb)
S.S.Lateef, Entomologist
M.P.Haware, Plant Pathologist
S.C.Sethi, Plant Breeder, Chickpea
N.P.Saxena, Agronomist (Physiology)
O.P.Rupela, Agronomist (Microbiology)
J.V.D.K.Kumar Rao, Agronomist (Microbiology) LEGOFTEN
G.V.Subba Rao, Research Scholar (until Oct)
C.S.Pawar, Entomologist, LEGOFTEN
A.M.Ghanekar, Plant Pathologist
Jagdish Kumar, Plant Breeder, Chickpea
S.Sithanantham, Entomologist (until Jul)
S.C.Gupta, Plant Breeder, Pigeonpea
P.N.Thapliyal, Sr Scientist (Pathology) (on contract from Apr)
M.V.Reddy, Sr Plant Pathologist
Y.S.Chauhan, Agronomist (Physiology)
S.B.Sharma, Plant Nematologist
M.D.Gupta, Sr Research Associate
N.V.Ratnam, Sr Research Associate
J.H.Miranda, Sr Research Associate, Chickpea
Sheila Vijay Kumar, Sr Research Associate (until Feb)
L.Krishna Murthy, Sr Research Associate
M.Chenchi Reddy, Sr Research Associate
Nandita Sarkar, Postdoctoral Fellow (until Sep)
S.K.Singh, Postdoctoral Fellow
F.B.Lopez, Postdoctoral Fellow
Sashi Gupta, Postdoctoral Fellow (from Oct)
G.S.Chipiengahalo, Research Scholar (from Mar)
Bele Gopal, Research Scholar
A.Schroth, Research Scholar

Groundnut Group

D.McDonald, Principal Plant Pathologist
J.P.Moss, Principal Cytogeneticist
D.V.R.Reddy, Principal Plant Virologist
J.H.Williams, Principal Plant Physiologist (on sabbatical until May)
J.A.Wightman, Principal Entomologist
S.N.Nigam, Principal Plant Breeder
F.Waliyar, Asst Principal Plant Pathologist
L.J.Reddy, Plant Breeder

P.Subrahmanyam, Plant Pathologist (on leave)
P.T.C.Nambiar, Microbiologist
P.W.Amin, Coordinator and Entomologist, LEGOFTEN
G.V.Ranga Rao, Entomologist
A.K.Singh, Cytogeneticist
V.K.Mehan, Plant Pathologist (on sabbatical from May)
D.C.Sastri, Cytogeneticist (on sabbatical from Jan)
M.J.Vasudeva Rao, Plant Breeder
S.L.Dwivedi, Plant Breeder
R.C.Nageswara Rao, Plant Physiologist
V.M.Ramraj, Plant Physiologist
N.Sivananda Reddy, Sr Research Associate
Y.Sudhakar, Postdoctoral Fellow
C.S.Gold, Postdoctoral Fellow
R.A.Naidu, Postdoctoral Fellow
W.R.Sacks, Postdoctoral Fellow (from May)
J.Watterott, Research Scholar
T.Shanower, Research Scholar
Zhang Xinyan, Research Scholar (from May)
Ulrich Hartman, Research Scholar
Ngugen Hai Nam, Research Scholar (from Jun)

Syria

K.B.Singh, Principal Chickpea Breeder
M.P.Haware, Principal Chickpea Pathologist

Pakistan

M.S.Rahman, Principal Chickpea Breeder/ Plant Pathologist

Resource Management

Program Office

J.L.Monteith, Program Director
S.K.Sharma, Sr Research Associate
L.Mohan Reddy, Sr Research Associate
R.S.Aiyer, Sr Adm Officer
S.Ramachandran, Adm Officer

Agronomy Group

S.M.Virmani, Principal Agroclimatologist
C.K.Ong, Principal Agronomist
D.R.Butler, Principal Microclimatologist (from Jul)
M.M.Anders, Principal Production Agronomist (from Dec)
R.Tabo, Principal Agronomist (until Apr)
Piara Singh, Soil Scientist
A.K.S.Huda, Agroclimatologist
A.Ramakrishna, Agronomist
A.A.H.Khan, Engineer
J.N.Daniel, Postdoctoral Fellow (from Sep)
J.C.W.Odongo, Postdoctoral Fellow (from Nov)

Soil Group

J.R.Burford, Principal Soil Chemist
K.B.Laryea, Principal Soil Physicist
G.D.Smith, Principal Soil Scientist, ICRISAT/QDPI
K.K.Lee, Principal Microbiologist
A.Schutt, Asst Principal Engineer (ICRISAT/University of Hamburg)
K.L.Sahrawat, Soil Chemist
T.J.Rego, Soil Scientist
D.P.Verma, Soil Scientist/Soil Chemist, ICRISAT/IFDC (on contract from Jul)
Sardar Singh, Soil Scientist
Prabhakar Pathak, Agricultural Engineer (on sabbatical from Sep)
K.L.Srivastava, Agricultural Engineer
R.C.Sachan, Agricultural Engineer
R.K.Bansal, Agricultural Engineer (until Oct)
N.K.Awadhwal, Agricultural Engineer/Soil Physicist
V.M.Mayande, Engineer (until Jun)
S.P.Wani, Microbiologist
M.Bonsu, Postdoctoral Fellow
G.W.L.Jayakumar, Research Scholar
S.Shailaja, Research Scholar (until Dec)

Economics Group

T.S.Walker, Principal Economist
P.J.Matlon, Principal Economist (until Aug)
R.A.E.Müller, Principal Economist
J-J.Baidu-Forson, Assistant Principal Economist (until Nov)
A.A.Adesina, Assistant Principal Economist (from Dec)
N.S.Jodha, Sr Economist (on leave)
R.P.Singh, Economist (on sabbatical until Apr)
M.Asokan, Sr Research Associate (on study leave)
K.G.Kshirsagar, Sr Research Associate (on study leave)
K.V.Subba Rao, Sr Research Associate
M.J.Bhende, Sr Research Associate (until Jan)
V.Bhaskar Rao, Sr Research Associate
P.Parthasarathy Rao, Sr Research Associate
A.G.Mengesha, Research Scholar
Jan Everet Bakker, Research Scholar (from May to Dec)

Support Programs

Biochemistry

R.Jambunathan, Principal Biochemist and Program Leader
Umaid Singh, Biochemist
V.Subramanian, Biochemist (on leave from Nov)

S.Sivaramakrishnan, Biochemist
P.Subrahmanyam, Sr Adm Officer (until Dec)
Santosh Gurtu, Sr Research Associate
M.S.Kherdekar, Sr Research Associate
S.Suryaprakash, Sr Research Associate
T.R.K.Satyanarayana, Adm Officer (from Dec)

Electron Microscopy

A.K.Murthy, Engineer

Genetic Resources

M.H.Mengesha, Principal Germplasm Botanist and Program Leader
K.E.Prasada Rao, Sr Botanist
R.P.S.Pundir, Botanist
V.Ramanatha Rao, Botanist
S.Appa Rao, Botanist
P.Remanandan, Botanist (on sabbatical from Jul)
T.R.K.Satyanarayana, Adm Officer (until Dec)
Y.Saideshwara Rao, Postdoctoral Fellow (until Dec)
Abid Sultana, Research Scholar
Surendra Mohan, Sr Adm Officer (from Dec)

Plant Quarantine

N.C.Joshi, Chief Plant Quarantine Officer (on contract)
Upendra Ravi, Sr Research Associate
N.Rajamani, Sr Adm Officer (until Mar)
V.S.Raju, Adm Officer (from Dec)

Fellowships and Training

D.L.Oswalt, Principal Training Officer and Program Leader
B.Diwakar, Sr Training Officer
T.Nagur, Sr Training Officer
S.K.Dasgupta, Sr Training Officer
Faujdar Singh, Training Officer

Information Services

D.A.Fuccillo, Head (until Aug)
J.B.Wills, Research Editor (on sabbatical, Jun-Dec)
Susan D. Hall, Research Editor (Acting Head Aug-Dec)
S.M.Sinha, Asst Manager, Art and Production
D.R.Mohan Raj, Sr Editor
J.J.Abraham, Editor
V.Sadhana, Editor
G.K.Guglani, Sr Art Visualizer
T.R.Kapoor, Sr Composing Supervisor
A.Antonisamy, Printshop Supervisor
A.B.Chitnis, Sr Photographer
N.V.N.Chari, Adm Officer (until Dec)
A.N.Venkataswami, Sr Adm Officer (from Dec)

Statistics

Murari Singh, Statistician (on sabbatical from Aug)

Computer Services

J.W.Estes, Computer Services Officer
S.M.Luthra, Manager (Computer Services)
J.Sai Prasad, Asst Manager (Computer Services)
T.B.R.N.Gupta, Senior Computer Programmer/Analyst
S.V.Nanda Kishore, Computer Programmer/Analyst (from Dec)
E.A.Vinod Kumar, Computer Programmer/Analyst
G.Subba Raju, Computer Programmer/Analyst (from Nov)

Library and Documentation Services

L.J.Haravu, Manager
P.K.Sinha, Sr Documentation Officer-II
P.S.Jadhav, Sr Library Officer
S.Prasannalakshmi, Sr Library Officer
R.G.Naidu, Documentation Officer
V.Venkatesan, Library Officer (on leave)

Housing and Food Services

D.A.Evans, Manager
S.Mazumdar, Asst Manager (Food Services)
B.R.Revathi Rao, Asst Manager (Housing)
D.V.Subba Rao, Asst Manager (Warehouse)
D.N.Sar, Canteen Officer
N.V.N.Chari, Adm Officer (from Dec)

Physical Plant Services

V.P.McGough, Manager (on secondment from Jul)
W.B.Symons, Principal Engineer (until Jun)
Sudhir Rakhra, Chief Engineer (Civil)
D.Subramaniam, Chief Engineer (Electrical) Manager (Acting) (from Jul)
N.S.S.Prasad, Sr Engineer (Electronics and Instrumentation)
A.R.Das Gupta, Sr Engineer (Communication) (on leave from Apr)
D.C.Raizada, Sr Engineer (Airconditioning)
A.N.Singh, Engineer (Heavy Equipment and Tractors) (on leave from Nov)
S.W.Quader, Engineer (Office Equipment)

K.R.C.Bose, Engineer (Civil)
K.Satyanarayana Raju, Engineer (Machineshop)
V.Madhusudan Rao, Engineer (Electronics and Instrumentation)
Y.Chiranjeevi Rao, Engineer (Electrical)
R.Parameswaran, Engineer (Auto) (from Aug)
S.P.Jaya Kumar, Sr Adm Officer

Farm Development and Operations

D.S.Bisht, Manager
S.N.Kapoor, Manager (Farm Operations) (on leave from Nov)
S.K.Pal, Sr Plant Protection Officer II
K.Ravindranath, Sr Engineer (Farm Machinery)
M.Prabhakar Reddy, Sr Agricultural Officer
N.V.Subba Reddy, Sr Horticulture Officer
M.C.Ranganatha Rao, Sr Engineer
S.Abid Ali Khan, Agricultural Officer
C.Rama Reddy, Agricultural Officer
Akbar Pasha, Engineer
S.C.Gupta, Engineer
V.S.Raju, Adm Officer (until Dec)
A.Hameed, Adm Officer (from Dec)

West African Programs

ICRISAT Sahelian Center, Niger

Administration

R.W.Gibbons, Executive Director, West African Programs, and Director, ICRISAT Sahelian Center
M.G.Wedeman, Regional Adm Officer (on special assignment until Feb)
A.R.Das Gupta, Manager, Physical Plant Services (from Nov)
A.Jagne, Regional Adm Officer (from Apr)
M.Adjei-Fah, Adm Secretary
M.D.Diallo, Regional Fiscal Officer
J.Banji, Purchase Officer (On special assignment, from Jan)
I.Agani, Accountant
Solange Delanne, Executive Asst (Liaison)
I.J.Cachalo, Bilingual Secretary
K.A.Moussa, Personnel and Transport Officer

Research Programs

Pearl Millet Improvement Program

K.Anand Kumar, Principal Millet Breeder and Team Leader
L.K.Fussell, Principal Millet Agronomist
S.O.Okiror, Principal Millet Breeder/Regional Trials Officer
J.Werder, Principal Millet Pathologist
M.J.Lukefahr, Principal Millet Entomologist
M.Mahamane, Bilingual Secretary
L.Marchais, Principal Geneticist (ORSTOM)
S.Tostain, Principal Geneticist (ORSTOM)
T.J.Stomph, Sr Research Asst (until Nov)
A.A.Cisse, Research Asst (from Jul)

Groundnut Improvement Program

B.J.Ndunguru, Principal Groundnut Agronomist and Team Leader
D.C.Greenberg, Principal Groundnut Breeder
P.Subrahmanyam, Principal Groundnut Pathologist

Resource Management Program

C.Renard, Principal Agronomist and Team Leader
M.C.Klaij, Principal Soil and Water Management Scientist
M.V.K.Sivakumar, Principal Agroclimatologist (on sabbatical until Nov)
R.J.Van Den Beldt, Principal Agronomist/Agroforestry
A.Bationo, Principal Soil Chemist (IFDC)
B.R.N'tare, Principal Cowpea Breeder/Agronomist (IITA)
Jane C.Hopkins, Visiting Scientist (IFPRI)
J.Lambourne, Principal Animal Nutritionist, Special Consultant (ILCA) (from Sep)
M.Welte, Program Corodinator, University of Hohenheim (from May)
Jane Toll, IBPGR Field Officer for West Africa
V.Watt, IBPGR Collector for the Sahel (until Aug)
P.Ouedraogo, Sr Research Asst

Support Programs

Farm Operations

P.G.Serafini, Research Farm Manager (on sabbatical from Aug)
R.Van Midde, Technical Asst (SNV)
P.Koudogbo, Chief Mechanic (until Jul)
J.Henry, Training Consultant (Mechanic) (from Nov)

Construction

B.D.Marvaldi, Project Development Officer (until Jul)
V.P.McGough, Facilities Unit Manager (from Aug)
A.Schulz, Project Development Officer (until Oct)

Statistics

B.Gilliver, Principal Statistician
G.Ouoba, Computer Programmer

Information/Documentation

C.Giroux, Regional Information Officer

West African Sorghum Improvement Program (WASIP)

Mali (transferred from Burkina Faso in June)

Administration

C.M.Pattanayak, Principal Sorghum Breeder and SAFGRAD/ICRISAT Coordinator (until Aug)
A.Schulz, Administrator (from Oct)

Research

K.V.Ramaiah, Principal Cereal Breeder—*Striga* and Acting Team Leader (from Aug)
D.S.Murty, Principal Sorghum Breeder (until Apr)
M.D.Thomas, Principal Sorghum Pathologist (Burkina Faso until Dec)
S.N.Lohani, Principal Millet Breeder (on sabbatical from Apr)
G.Hoffman, Principal *Striga* Agronomist (CIRAD)

Nigeria

Administration

O.Ajayi, Principal Sorghum Entomologist and Team Leader
A.Banerji, Adm Officer (from Nov)

Research

D.S.Murty, Principal Sorghum Breeder (from Apr)
R.Tabo, Principal Sorghum Agronomist (from Apr)
S.N.Kapoor, Farm Manager (from Nov)

Mali Bilateral Program

S.V.R.Shetty, Principal Agronomist and Team Leader
N.F.Beninati, Principal Breeder

Southern Africa Programs

SADCC Regional Sorghum and Millet Improvement Program, Zimbabwe

L.R.House, Executive Director, Southern Africa and Project Manager, SADCC/ICRISAT Program
S.P.Ambrose, Regional Adm Officer
A.B.Obilana, Principal Sorghum Breeder
S.C.Gupta, Principal Millet Breeder
W.A.J.de Milliano, Principal Cereals Pathologist
M.Osmanzai, Principal Cereals Agronomist
K.Leuschner, Principal Cereals Entomologist
D.Rohrbach, Principal Economist (from Feb)
H.Ssali, Soil Scientist (IFDC)
Manel I. Gomez, Principal Food Technologist (from Jul)
F.York, Station Development and Operations Officer
C.M.Matanyaire, Station Management and Development Officer (from Aug)
E.Monyo, Postdoctoral Fellow
W.K.Morgan, Asst Adm Officer (until May)
Z.M.Mhlanga, Asst Adm Officer (from Sep)
R.Nxumalo, Sr Accountant (until Jun)
N.Mwamuka, Research Technician - Grade II
P.Chingombe, Research Technician - Grade II
F.Munaku, Research Technician - Grade II

Regional Groundnut Improvement Program, Malawi

K.R.Bock, Principal Groundnut Pathologist and Team Leader
G.L.Hildebrand, Principal Groundnut Breeder

Writing and editing: J.J. Abraham. Design: S.M. Sinha. Artwork: A.A. Majid and P. Satyanarayana. Typesetting: Composing Unit staff. Printing: Printshop staff. Photographs: A.B. Chitnis pages 1 (top), 7 (top), 8 (both), 9 (top and bottom left), 12 (bottom), 13 (both), 14 (top), 15 (top), 16 (bottom), 23 (bottom), 28 (both), 29 (top right and left), 32 (top), 39 (bottom), 43 (both), 44 (all except bottom left), 45 (both), and 46 (top); Onkar Singh pages 1 (bottom), 19, and 36; R. Bandyopadhyay page 4 (top), 5 (both), and 6 (bottom); Electron Microscope Unit page 4 (micrographs); Suresh Pande page 6 (inset); D.V.R. Reddy page 7 (inset) and 37 (top), B.D. Hall page 9 (bottom right); C. Paul page 10; G.V. Ranga Rao page 12 (top); H.A. van Rheenen 14 (bottom); Belum V.S. Reddy page 16 (top); D.S. Murty page 16 (middle); Laxman Singh pages 17 and 18; C.K. Ong pages 22, 26 (both), 27 (top), and 29 (bottom); H.S. Duggal page 23 (inset); O.P. Rupela page 24; C. Renard pages 27 (bottom) and 31 (all); P.W. Amin pages 32 (bottom) and 33 (all); C.S Pawar page 34; D.G. Faris pages 37 (inset), 38 (top and middle), and 39 (top); M.J. Vasudeva Rao page 38 (bottom); S. Appa Rao page 40 (top); K.E. Prasada Rao pages 40 (bottom) and 42 (bottom); R.P.S. Pundir page 41; M.I. Gomez page 44 (bottom left); and K.C. Jain page 46 (bottom). Other slides used are contributions from collections of ICRISAT scientists or Photo Laboratory.