FARMING SYSTEMS

# ICRISAT ANNUAL REPORT 1975-76

SORGHUM

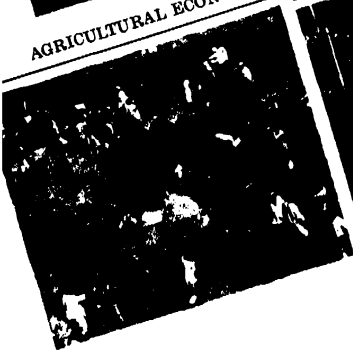
PIGEONPEA

PEARL MILLET

CHICKPEA

GROUNDNUT

AGRICULTURAL ECONOMICS



INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

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# ANNUAL REPOR
## 1975-7(

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1-11-256 BEGUMPET, HYDERABAD-500016 (A.P.), INDI

## About This Report

This is the third annual report published by the International Crops Research Institute for the Semi-Arid Tropics. Printed for world-wide distribution, the report covers ICRISAT's development and activities from 1 April 1975 to 31 May 1976.

Detailed reporting of the extensive activities of ICRISAT's many research support units is beyond the scope of this volume, but a comprehensive coverage of ICRISAT's core research programs is included. Detailed annual reports have been prepared for limited distribution by each unit.

ICRISAT receives support from the Consultative Group on International Agricultural Research. The responsibility for all aspects of this publication rests with ICRISAT. Mention of particular pesticides, fungicides, herbicides, and other chemicals does not necessarily imply endorsement of or discrimination against any product by the Institute. The correct citation for this report is International Crops Research Institute for the Semi-Arid Tropics, 1976. *ICRISAT Annual Report 1975-1976*. Hyderabad, India.

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# ICRISAT Governing Board

# ICRISAT Personnel— May 31, 1976

## Administration

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J. S. Kanwar, Ph.D., associate director
R. C. McGinnis, Ph.D., associate director
S. K. Sahgal, IAS, principal administrator
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R. Vaidyanathan, purchase and supplies officer
S. K. Mukherjee, B.Sc. (Eng'g.), personnel manager
R. G. Rao, records management
B. Diwakar, Ph.D., scientific liaison officer
S. B. C. M. Rao, B.Com., travel officer
J. Pearson, transport officer
P. W. Curtis, Col., (Grad. IMA, Dehradun), security officer
V. Balasubramanian, executive assistant to the director
N. Rajamani, New Delhi liaison representative

## Crop Improvement and Production

### Cereals

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D. J. Andrews, B.Sc. (Hons), D.A.S., D.T.A., plant breeder (millets)
P. K. Lawrence, Ph. D., assistant plant breeder (sorghum)
B. W. Hare, Ph. D., assistant plant breeder (millets)
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J. D. Skinner, Ph.D., assistant entomologist
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V. S. Bhatnagar, Ph.D. (entomology)
K. N. Rao, Ph.D. (pathology)
S. D. Singh, Ph.D. (pathology)
R. P. Thakur, Ph.D. (pathology)

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A. R. Sheldrake, Ph.D., physiologist
Y. L. Nene, Ph.D., pathologist
P. J. Dart, Ph.D., microbiologist
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K. B. Singh, Ph.D., associate plant breeder (chickpea)

*Research Associates*

L. J. Reddy, Ph.D. (pigeonpea)
K. B. Saxena, Ph.D. (pigeonpea)
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*Research Associates*

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R. C. Sachan, M.Tech. (Agr. Eng'g), (soil and water management)
P. N. Sharma, M.Tech., (soil and water management)
Piara Singh, M.Sc., (soil science)
Sardar Singh, Ph.D. (soil science)
K. L. Sahrawat, Ph.D. (soil science)
T. J. Rego, Ph.D. (soil science)
K. Prabhakara Rao, Ph.D. (agroclimatology)
Harbans Lal, M.Tech., (farm machinery and power)

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D. S. Bisht, B.Sc. (Ag. & AH)(Hons.), farm operations supervisor
D. N. Sharma, B.Sc. (Ag.) Eng. & Tech., farm development supervisor

## Agricultural Economics

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H. P. Binswanger, Ph.D., economist
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H. S. Sandhu, Ph.D., associate economist

*Research Associates*

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V. T. Raju, Ph.D.
S. L. Bapna, Ph.D.
B. C. Barah, Ph.D.

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A. S. Murthy, Ph.D., associate training officer

## Statistics and Computer Services

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J. W. Estes, M.S., computer services officer
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*Research Associates*

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Umaid Singh, Ph.D.

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S. M. Sinha, N.Dip. Com.Art , Artist
H. S. Duggal, Photographer

## Library

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F. J. Bonhage, construction supervisor
Sudhir Rakhra, B.E.,
engineering associate (civil)
B. H. Alurkar, B.E. (Civil), M.I.C.E. (Ind.),
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H. C. Tewari, M.S.A., assistant engineer
D. Subramanian, B.E. (Elec.),
electrical engineer
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V. Lakshmanan, executive assistant

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Senegal

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Upper Volta

J. A. Frowd, Ph.D., plant pathologist,
Upper Volta

S. A. Clarke, M.S., field trials officer,
Mali

S. O. Okiror, assistant plant breeder,
Nigeria

**Acronyms used in this Annual Report:**

| | |
|---|---|
| AICMIP | All-India Coordinated Millets Improvement Project |
| AICPIP | All-India Coordinated Pulses Improvement Project |
| AICRPDA | All-India Coordinated Research Project on Dryland Agriculture |
| AICSIP | All-India Coordinated Sorghum Improvement Project |
| ALAD | Arid Land Agricultural Development program (Middle East, North Africa) |
| APAU | Andhra Pradesh Agricultural University (India) |
| CEAO | West African Economic Community |
| CFTRI | Central Food Technological Research Institute (India) |
| CGIAR | Consultative Group on International Agricultural Research |
| CIMMYT | International Maize and Wheat Improvement Center |
| CPPTI | Central Plant Protection Training Institute (India) |
| CSIRO | Commonwealth Scientific and Industrial Research Organization (Australia) |
| DPAP | Drought-Prone Area Programme (India) |
| ECIL | Electronics Corporation of India, Limited |
| IARI | Indian Agricultural Research Institute |
| IBPGR | International Board for Plant Genetic Resources |
| ICAR | Indian Council of Agricultural Research |
| IDRC | International Development Research Centre (Canada) |
| IITA | International Institute of Tropical Agriculture |
| IPMAT | International Pearl Millet Adaptation Trials |
| IPMDMN | International Pearl Millet Downy Mildew Nurseries |
| IRAT | Institute for Tropical Crops Research (France) |
| NIN | National Institute of Nutrition (India) |
| OAU/STRC | Organisation of African Unity/Scientific Technical and Research Commission |
| ODA | Overseas Development Agency (United Kingdom) (now MOD, Ministry of Overseas Development) |
| ORSTOM | Office for Overseas Scientific and Technical Research (France) |
| SAFGRAD | Semi-Arid Food Grain Research and Development in Africa |
| SAT | Semi-Arid Tropics |
| UNDP | United Nations Development Programme |
| UNEP | United Nations Environment Programme |
| USAID | United States Agency for International Development |
| VLS | Village-Level Studies |
| WHO | World Health Organization |

*Agricultural production in the Semi-Arid Tropics is dependent, to a great degree, on the successful collection, storage, and use of excess rainfall.*

# Director's Introduction

Big news at ICRISAT during the past year —April 1975 through May 1976—included the weather. The 1975 rainy season, the monsoon, was record-breaking in several ways. It provided the most rainfall ever recorded for a September at Patancheru, where ICRISAT Center is located. October rainfall was double the 30-year average. This otherwise delightful situation provided a challenge in harvesting and drying the rainy season crops at ICRISAT Center, and made it difficult to maintain construction schedules for the new laboratories, administration building, training facilities, and staff housing going up there.

Dedication of Lake ICRISAT in April 1976 marked the completion of a major water-storage facility at the Center. Some 150 000 cubic meters of earth were rearranged to provide a storage basin 52 hectares in area and 110 hectare-meters in capacity. Lake ICRISAT will be the major source of irrigation water on the Center; even though the goal of ICRISAT's research effort is the improvement of agricultural production in rainfed agriculture, irrigation is needed to assure year-round growing conditions for accelerated crop-improvement programs. Special-purpose areas, such as the disease nurseries, isolated seed-increase plots, and other nursery areas will need occasional irrigation to protect the valuable research being conducted there. Irrigation also makes possible the growing of three generations of sorghum and millet each year, an important consideration in speeding up the development of new genotypes for testing under rainfed conditions. The major portion of the research farm will be devoted to development of seed and technology for low-input rainfed agriculture, with some 800 hectares of arable land available for this purpose.

Animal power, the only source of supplemental energy generally available to many

*ICRISAT's cooperative programs of training expanded during the year. This group of inservice trainees completed its work; its members are now involved in crop-improvement activities in their home nation of Nigeria.*

SAT farmers, received major emphasis during the past year. ICRISAT scientists, believing that optimum crop technology is possible with animal power, used bullocks and experimental implements to perform plowing, ridging, planting, and cultivating operations. They have discovered that there is plenty of room for improvement in the implements available to SAT farmers, and the farm implement program of ICRISAT is now in the early development stage.

Bullock power also figured predominantly in a project designed to study cost of development of resources, using exclusively those resources available to the farmer. During the dry season of 1975, a small representative watershed of 15 hectares was developed completely by bullock and human power.

ICRISAT's family of crops—sorghum, pearl millet, pigeonpea, and chickpea—was joined by a fifth during the year. A research proposal covering all aspects of a groundnut program was approved by the governing board early in 1976. A groundnut scientist has joined the staff, and is busy planning a program that will incorporate disease resistance into cultivars with high yield potential. As sources of human and animal foods and as an economic crop, groundnuts are one of the most important legumes in the SAT. Yields are exceptionally low, however, compared to production in other areas, and ICRISAT's early efforts will be focused on yield improvement through disease resistance.

The Village-Level Studies program, started early this year by the Agricultural Economics unit, is already yielding data that will help ICRISAT scientists understand the numerous and sometimes mysterious forces that mold life in SAT villages. An understanding of farmer motivation and behavior is essential if ICRISAT is to succeed in its mission of providing an agricultural technology that is pragmatically oriented to the village and the real-life conditions of the farmer. Data analysis by all research units is being enhanced by the use of ICRISAT's recently installed computer.

*UNDP-supported projects at CIMMYT and ICRISAT were reviewed by the Policy Advisory Committees meeting in joint session at Hyderabad. The joint-meeting approach is a useful technique for achieving greater collaboration in the global effort to increase food production.*

ICRISAT was pleased to host, in cooperation with CIMMYT, a meeting of two Policy Advisory Committees of the United Nations Development Program in September. The Committees met as a single body to review UNDP-supported work at ICRISAT and CIMMYT. The research program on sorghum and millets, both in India and in West Africa, was reviewed. The ICRISAT cereals team received recommendations on topics ranging from pest and disease resistance to grain quality and international cooperation. The joint-meeting approach, according to the UNDP visitors, permitted greater insights into the programs at ICRISAT and at CIMMYT, and represents a useful technique for achieving greater collaboration in the global effort to increase food production.

Developments in ICRISAT's training program expanded during the year. Eleven persons—eight from Africa and three from Asia—completed the in-service training program, and ten persons completed programs of shorter duration. Several groups of specialists participated in special courses arranged in cooperation with agricultural agencies of the Government of India. Twelve agricultural workers from five Francophone African nations arrived to begin an intensive English study program in preparation for in-service training. A program for Research Fellows, essentially post-graduate in nature, has been initiated, as has a program for Research Scholars. The latter program is for students working toward M.Sc. or Ph.D. degrees in a graduate school of a cooperating university; the thesis research is performed on a subject of interest to SAT agriculture under the direction of an ICRISAT scientist.

Significant advances were made in ICRISAT's partnership programs with other nations during the year. An Associate Director for International Cooperation was appointed, and the ICRISAT West African Sorghum and Millet Improvement project, made possible by UNDP funding, received top priority and major emphasis. Dr. Claude Charreau of IRAT was deputed to head the project, and he has established headquarters in Dakar, Senegal. Eleven nations—Senegal, Upper Volta, Niger, Nigeria, Gambia, Mauritania, Ghana, Togo, Chad, Benin, and Cameroon—are cooperating in this effort. Scientific teams have been or will be located in Nigeria, Senegal, Upper Volta, and Niger; these teams will work with scientists in national programs throughout West Africa.

Cooperative activities are also underway in East Africa, South America, and a number of Asian nations. As always, ICRISAT owes a special vote of thanks to its host nation—India—for the many formal and informal cooperative efforts that are vital to ICRISAT's mission in the SAT.

## ICRISAT's Five Crops

| | | | | | |
|---|---|---|---|---|---|
| Latin | *Sorghum bicolor* (L.) Moench | *Pennisetum americanum* (L.) K. Schum | *Cajanus cajan* (L.) Mill. | *Cicer arietinum* (L.) | *Arachis hypogaea* (L.) |
| English | Sorghum, durra milo, shallu, kafir corn, Egyptian corn, great millet, Indian millet | Pearl millet, bulrush millet, cattail millet, spiked millet | Pigeonpea, red gram | Chickpea, Bengal gram, gram, Egyptian pea, Spanish pea, chestnut bean, chick, caravance | Groundnut, peanut |
| French | Sorgo | Petit mil, millet mil a chandelles | Pois d'Angole | Pois chiche | l'arachide |
| Portuguese | Sorgo | Milheto | Guando | | Amendoim |
| Spanish | Sorgo, zahina | Milo perla, millo | Gandul | Garbanzo, garavance | Mani |
| Hindi | Jowar, jaur | Bajra | Arhar, Tur | Chana | Mungphali |

# Research Highlights

## Sorghum

Recurrent selection of random-mating composite sorghum populations is paying off. Best lines from the Fast Lane populations produced from 5 000 to 5 500 kg/ha at high fertility, and 3 000 to 3 500 kg/ha at low fertility. Seven populations—RS/R, RS/B, US/R, US/B, Serere Elite, Tropical Composite, and High Altitude—tested in India, Thailand, and Uganda showed good stability across environments. Individual lines produced 3 800 to 4 500 kg/ha at all sites.

In the pedigree program, 26 adapted varieties from several countries were crossed with lines showing increased resistance to shoot fly, stem borer, and midge. However, population breeding using recurrent selection appears to be the best long-term approach for combining shoot-fly and stem-borer resistance with yield and grain quality. Selected lines carrying good grain quality, high yield, and either $ms_3$ or $ms_7$ were crossed with sources resistant to shoot fly, stem borer, and midge to create such a population. Genetic tests indicate that the field-screening technique for shoot-fly resis-

*Contracts for all major buildings in ICRISAT's physical plant were negotiated in 1975, and construction was well underway by the end of the year.*

tance can be used effectively in $S_1$ and $S_2$ lines, but not in half-sib rows

In international testing, some of the AICSIP lines did well at several sites, including West Africa. Some Uganda material did well, especially within 10° latitude of the equator.

Some of the grain-grass sorghums are now in the $F_5$ generation, and as a group are showing more cold tolerance for post-rainy season plantings and some have excellent drought endurance. Non-senescent types which ratoon easily have also appeared. In the work with tetraploid grain sorghums, progress was made in developing photoperiod insensitive types with better grain quality, and crosses and backcrosses were made to halepense types to move the excellent adaptive characteristics into the cultivated crop.

During the post-rainy season, germplasm scientists collected 147 new farmers' types in Andhra Pradesh, bringing the total number of accessions in the sorghum germplasm collection to 14240. The entire collection, other than the new accessions, was evaluated for principal morphological characteristics.

ICRISAT pathologists screened more than 4000 germplasm and breeding lines for grain-mold resistance, based on natural mold development and inoculation with *Fusaria semitectum* and *Curvularia lunata*. Three lines—IS-9327, 9333, and 9530—show very good resistance, and an additional 90 lines show good resistance. Microfloral and seed-treatment studies revealed that grain-mold infection may reduce germination to less than 5 percent in grain on which mold is evident, clean grain from moldy heads may show only 20 percent germination. Fungicidal treatment of molded seed does not improve its viability.

ICRISAT microbiologists are developing an assay system for identifying sorghum lines which stimulate nitrogen fixation. During the post-rainy season, 115 entries were grown under irrigated low-fertility conditions, nitrogenase activity of the washed root systems showed a variation of up to fortyfold among lines. High nitrogenase activity was noted in cultivars CSH-1 and CSH-5, and in *S halepense*.

## Pearl Millet

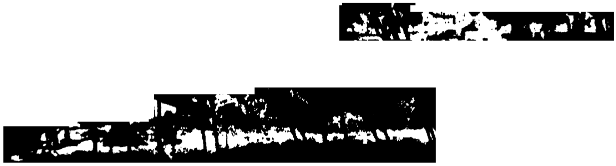
During 1975, ICRISAT breeders put considerable effort into conducting extensive breeding nurseries in northern and in southern India, as well as at ICRISAT Center, and a limited amount of material was tested by the ICRISAT breeder in Upper Volta. By conducting trials at locations distant from Hyderabad, scientists were able to compare genotype reaction to various day lengths, day and night temperatures, moisture and soil differences, and other environmental conditions, as well as to screen for diseases prevalent in other areas of the SAT but not found at ICRISAT Center. From these trials, a group of inbred lines, hybrid parents, experimental varieties, three hybrids, and three synthetics have been assembled for next year's trials.

Some hybrid pollen parents were found in the composite progenies, and breeding for dwarfed versions is underway.

A vigorous attack on pearl millet diseases was initiated in 1975. Experiments in the development of reliable field-screening methods for resistance to downy mildew revealed that sporangial inoculum produced by highly susceptible infector rows planted 3 weeks prior to the test rows effectively inoculated the test material, this technique will enable the screening of large quantities of breeding materials in ordinary fields. Techniques for field inoculation of smut and ergot are under study.

ICRISAT pathologists also entered into a cooperative effort with pathologists from other research agencies to determine the role of seed transmission in the spread of downy mildew. Accurate knowledge in this regard is essential for safe movement of breeding material on a worldwide basis.

Genetic variability in growth attributes of 50 genotypes were recorded by ICRISAT physiologists, several types of drought reaction were noted, and two contrasting genotypes were studied in detail for differences in panicle and root development. In cooperation with breeders, 82 breeding lines complementary in yield attributes were selected for crossing. A



*The watertower will be one of ICRISAT Center's major landmarks; construction got underway with the pouring of this base of 150 cubic meters of mortar. The tower will supply water for laboratories, administrative quarters, and residences.*

total of 1700 genotypes were selected to undergo field evaluation for drought tolerance.

In the germplasm collection, a Working Collection of 340 entries representing a good range of source material for breeders was assembled and is now being evaluated in different environments. Additions to the germplasm bank were obtained during a collecting expedition in West Africa.

Three groups of material with wide ranges between individual lines in protein content were identified—the Working Collection (protein content ranging from 6 to 14.5%), Senegal Dwarf Synthetic (8.1 to 15.2%), and the "World" Composite (7.5 to 15%). Progeny of the "World" Composite population show good visual grain and head characteristics; in 1975 tests, these progeny performed well in terms of yield and disease resistance.

Testing of existing Indian hybrids and synthetics in rotation and intercropping patterns indicate that alternate-row cropping of early maturing pearl millet with slow-establishing medium or long-duration pigeonpea will increase the combined value over that of the crops grown separately by as much as 80 percent. However, the Indian hybrids were susceptible to ergot and poor in resistance to head molds. Some ICRISAT genotypes that did well in 1975 trials are to be tested for intercropping potential next year.

Fifty-seven lines of pearl millet and related species were assayed under low-fertility conditions for root nitrogenase activity; rates of up to 1.1 µmol/g dry root per hour were recorded, but large differences were noted within plots.

## Farming Systems

Using weather, soil, and evaporation data in a water-balance simulation model, the mean length of the growing season at ICRISAT Center was found to be 17 weeks on shallow red soils, 21 weeks on deep red soils, and 25 weeks on deep black soils. This information was used to develop a calendar for seedbed preparation and planting.

A computer-simulation technique that matches soil-moisture availability with growth duration and water needs of various crops provides a tool by which cropping systems may be matched with basic resources in any region for which moisture data is available.

Infiltration rates on red soils were found to be greater under broad-ridged conditions than on flat-planted areas. Red-soil infiltration rates generally exceed those of black soils, but runoff during the early rainy season (as well as annually) was lowest on black soils, probably because of deep cracks existing in black soils during the early rainy season and the tendency of red soils to surface-seal during intensive rainfall.

Animal-drawn tool carriers from several countries were adapted and tested in field-sized operations of plowing, harrowing, ridging, planting, and inter-row cultivation. A broad ridger for making 150-cm ridges and furrows was developed.

Cross-slope erosion, a problem in red soils during past rainy seasons, was eliminated with the use of a broad ridge-and-furrow system. The system has great flexibility for intercropping and planting of crops requiring various row widths and also facilitates land preparation.

The value of a small quantity of supplemental irrigation during the post-rainy season was demonstrated with tomatoes on red soil and with sorghum on black soils; yields were essentially doubled.

In intercropping experiments, the best combination was found to be a slow-establishing pigeonpea of 6 months' duration with a rapid-establishing early upright non-ratooning cereal, such as Setaria or pearl millet. The gross monetary value of double-cropping systems with a maize rainy-season crop plus post-rainy season relay crops was four times that of the post-rainy season crop in the system where the land lays fallow during the rainy season.

In the study of steps toward improved technology, it was observed that an improved sorghum cultivar was not of much advantage to farmers using traditional fertilization and soil and crop management practices; but with improved fertilization and improved crop and soil management, the improved sorghum cultivars far outyielded the local sorghums. With improved fertilization and soil and crop management technology, yields of the local varieties in some cases almost doubled.

A black-soil (Vertisol) watershed—BW7 of 15.4 hectares—was developed and five tanks constructed during the extended dry season, using animal power that is normally idle at this season and human labor, with a minimum of capital inputs.

Fallowing during the rainy season was seen to be a wasteful practice; runoff on a fallowed black-soil watershed was 24 percent, while on a ridged and cropped watershed it was less than 15 percent. The red-soil watersheds, however, lost as much as 30 percent water to runoff under the same conditions. Soil losses on fallowed black-soil areas were ten times (2.5 metric tons/ha) those on cropped black-soil watersheds with ridges and furrows.

Evapotranspiration for a double-cropping system (rainy season crop followed by post-rainy season crops) was 65 percent of rainfall; only 25 percent of the rainfall was utilized as evapotranspiration in a single post-rainy season crop.

A maize-chickpea double-crop system provided four times the income of the traditional post-rainy season cropping system. Pearl millet planted as a sole crop on ridges yielded 20 percent more than when flat-planted; the maize yields increased 10 percent when planted on ridges.

Rainfall-use efficiencies, expressed as gross crop value in Rs/cm of rainfall, ranged from for a single-crop traditional management system to 130 for double-cropping with improved soil, water, and crop management.

## Agricultural Economics

Village-level studies in Sholapur, Akola, and Mahboobnagar districts revealed that farmers hard hit with 2 or 3 years' drought will sell off their animals and frequently will leave their land and turn to farm or non-farm employment. The shortage of bullocks can delay subsequent farming operations and thus stand in the way of rehabilitating farmers, even when weather conditions are favorable for farming.

In studying how farmers in India adjust to periods of scarcity, it was observed that farmers in sequence first reduce consumption, use or dispose of existing stocks and inventory, sell or mortgage non-productive assets, and as a last resort sell the productive assets or migrate. These findings may have some implications for relief policies.

The VLS data also reveal that on some small holdings, farmers generally follow a mixture of two, three, or four crops, whereas on larger holdings they generally employ sole cropping. Sole cropping was also preferred in areas where irrigation was practiced. This suggests an increased utility of intercropping research in terms of benefit to small farmers.

# Weather at ICRISAT

## Rainfall

Daily and weekly[1] rainfall during rainy season 1975, as recorded at ICRISAT Center's agro-meteorological observatory, are plotted in Figure 1. The season was one of the wettest on record. Rainfall at the ICRISAT Center observatory totaled 1 045.5 mm; 1 265.7 mm was observed at one gauge located at the boundary of the Center. In only 4 of the past 50 years has annual precipitation exceeded 1 000 mm.

Monthly rainfall recorded at the ICRISAT Center observatory during the past 4 years, as well as the long-term average monthly precipitation, is plotted in Figure 2. Comparisons between years, as well as studies of the rainfall patterns within any year, show that the past 4 years have been characterized by many extreme conditions. The observed distributions quite vividly illustrate the uncertainty and lack of consistency of climate, especially rainfall, in the SAT.

The rainfall pattern in June produced considerable problems with regard to dry planting in the deep black soils. Early showers partially moistened the surface soil and caused germination of some of the seeds immediately after planting and subsequent death because of lack of moisture. Extremely poor stands, particularly with small-seeded crops like pearl millet and Setaria, was the result. The larger-seeded crops–sorghum and maize–could be planted deeper and less damage was observed.

Although the total rainfall during August was not unusual, 19 rainy days were observed and long continuous periods of wet and cloudy weather were experienced. September had a much higher rainfall, falling in 19 days. The total precipitation of 422 mm in September, a substantial amount of which occurred during high-intensity storms, provided excellent opportunities for testing the adequacy of designs for several land- and water-management systems on red and black soils. Rainfall was recorded on 18 days in October; the unusually wet weather created severe difficulties with regard to the harvest of rainy season crops, particularly millet and sorghum, as well as in the planting of post-rainy season crops such as chickpea and safflower.

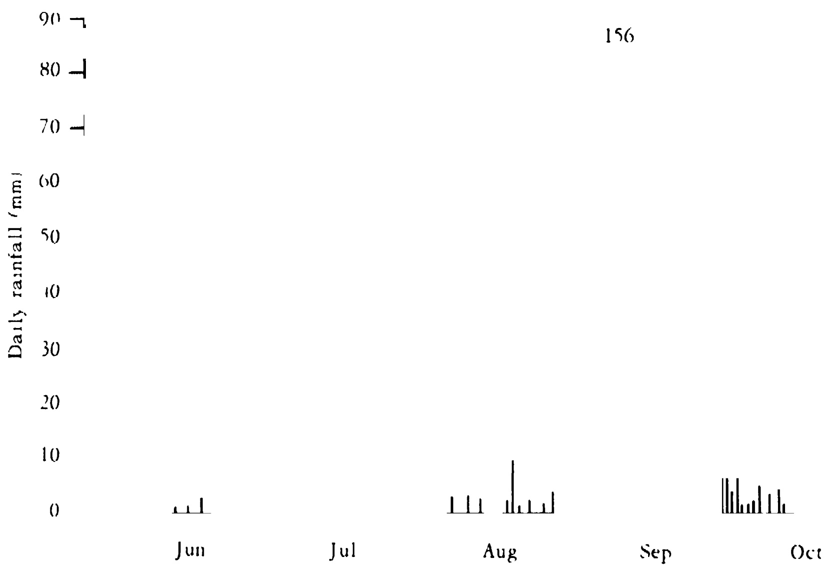
As in earlier years, an extremely high degree of variability was noticed between different rain gauges at ICRISAT Center during several storms in rainy season 1975. For example, on 4 August 36.4 mm of rainfall were measured at the southwest corner of the Center. Likewise, on 5 October, while 1.6 mm was recorded at the northern boundary of ICRISAT Center, 70.8 mm was measured at its southern boundary. Considerable variation was noticed within the black-soil research watersheds; on 5 July 15 mm were received on BW-1, while on BW-8 36 mm were recorded. These data confirm the necessity of an adequate raingauge network for moisture or rainfall-related research.

Rainfall conditions of the 1975 rainy season have shown a definite need for improved land- and water-management techniques to facilitate agricultural operations and to support plant growth, not only under conditions of limited rainfall or drought but also when precipitation is temporarily or continuously above normal, creating serious drainage problems.

## Rainfall Intensity

The rainy season in 1975 was characterized by relatively few high-intensity storms; the five maximum-intensity storms (intensity is derived from the maximum amount of rainfall received during any 30-minute period of a given storm) are plotted in Figure 3; the total quan-

[1] The "standard" weeks are consecutively numbered 7-day periods; Jan 1-7 is designated week 1, Jan 8-15 is designated week 2, etc; June 4-10 is standard week number 22.



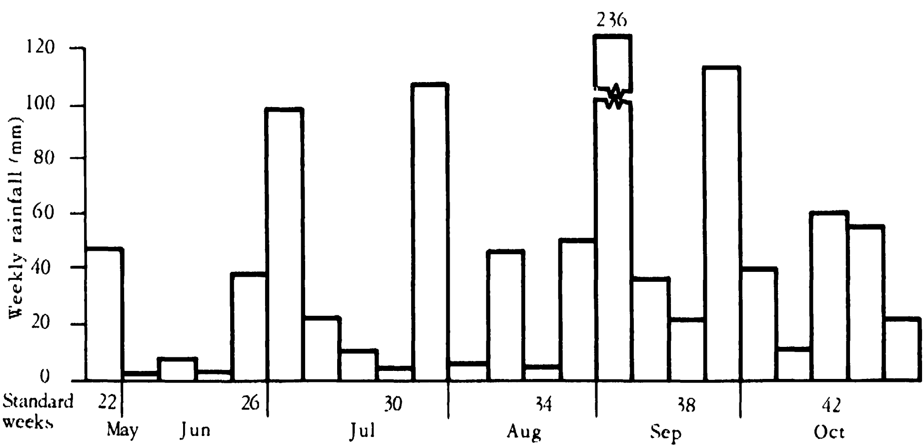




**Figure 1. Daily and weekly rainfall at ICRISAT Center, rainy season 1975.**

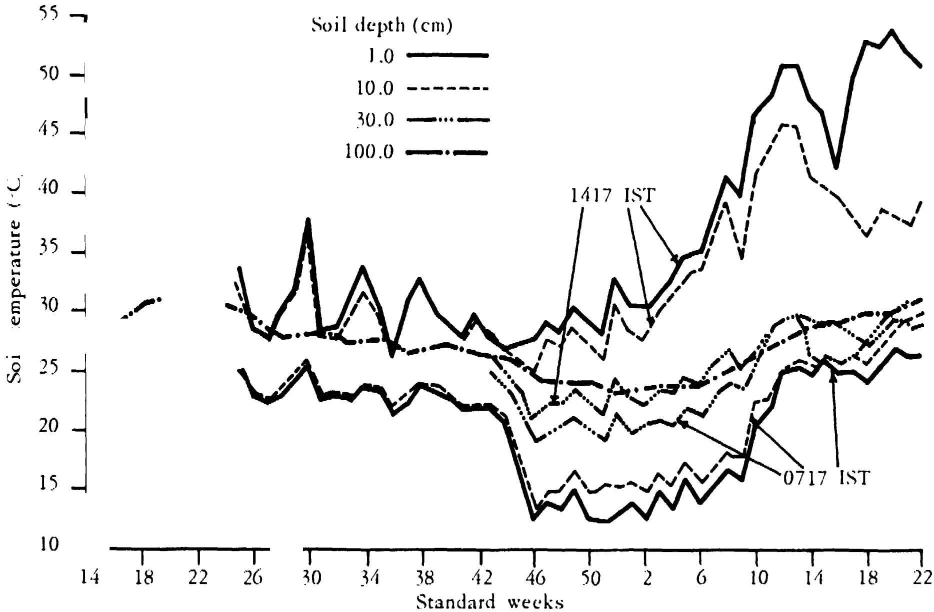



**Figure 5. Weekly average soil temperatures, ICRISAT Center, 1975-1976.**

November, when the rains receded, bright sunshine on average was less than 9 hr/day. From November to March, approximately 10 hours of bright sunshine was recorded on the average day.

## Evaporation

Highest open-pan evaporation rates (Fig 8) were observed during May; a maximum daily evaporation of 19.2 mm was recorded on 25 May 1975. It is interesting to note the rather extreme fluctuations occurring during rainy versus dry periods in the rainy season. On some rainy days in August, evaporation rates as low as 1.7 mm/day were recorded; evaporation rates during subsequent dry periods were several times higher (up to 8 mm/day). Evaporation rates (and therefore evaporative demands) during drought periods in the rainy season can apparently reach very high values and intensities; this phenomena has serious implications for moisture stress which, during the rainy season, may occur at relatively high levels of soil-moisture availability.

## Humidity

Humidity measurements for 0717 and 1417 hours are presented in Figure 9. From early July to early October, relative humidity recorded in the morning was constantly high (about 90%); the afternoon values were in the order of 70 to 80 percent. However, during November the relative humidity measured in the afternoon decreased to values between 30 and 40 percent.

## Dew

Only about 3.5 mm of dew was recorded in November, and a total of 2.5 mm of dew was observed in the months of December and January.

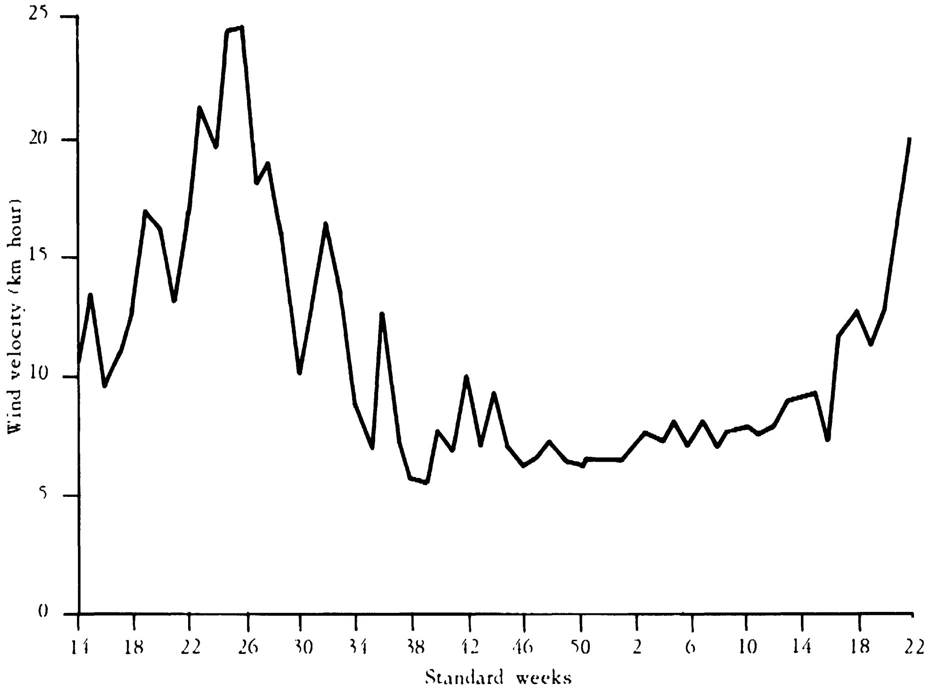



**Figure 6. Weekly average wind velocity, ICRISAT Center, 1975-1976.**

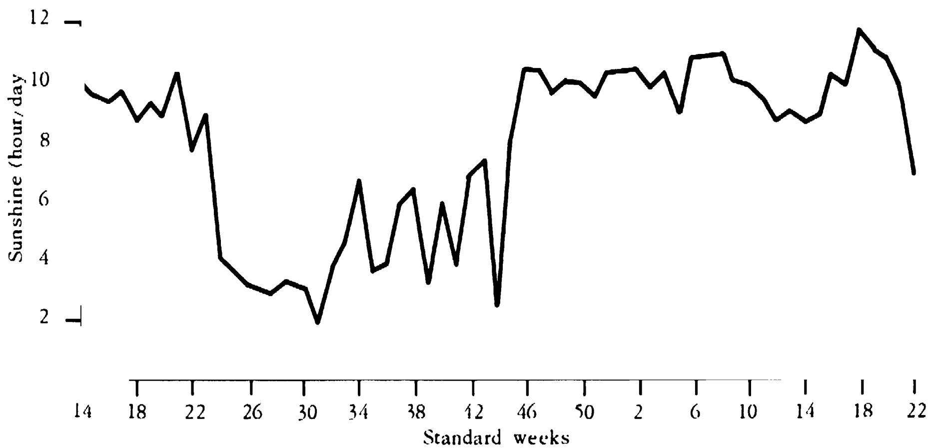



**Figure 7. Weekly average bright sunshine, ICRISAT Center, 1975-1976.**

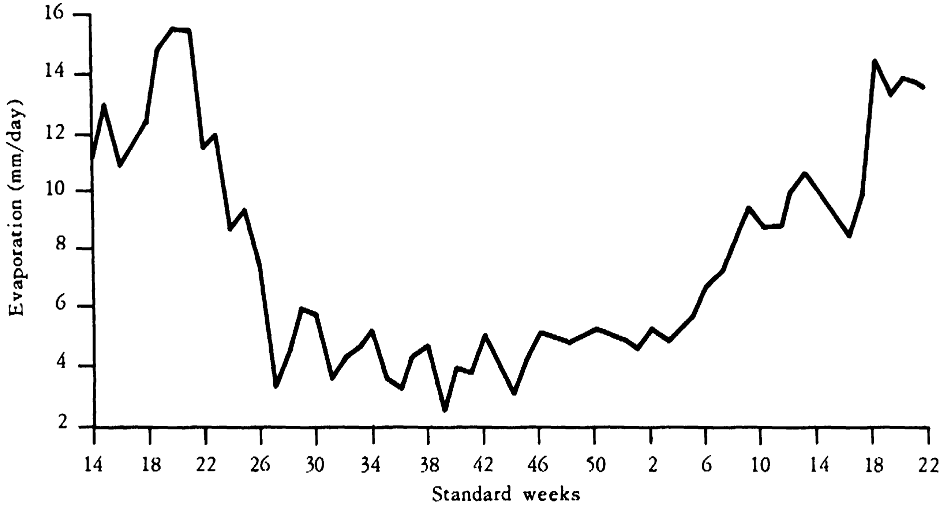



**Figure 8. Weekly average evaporation, ICRISAT Center, 1975-1976.**

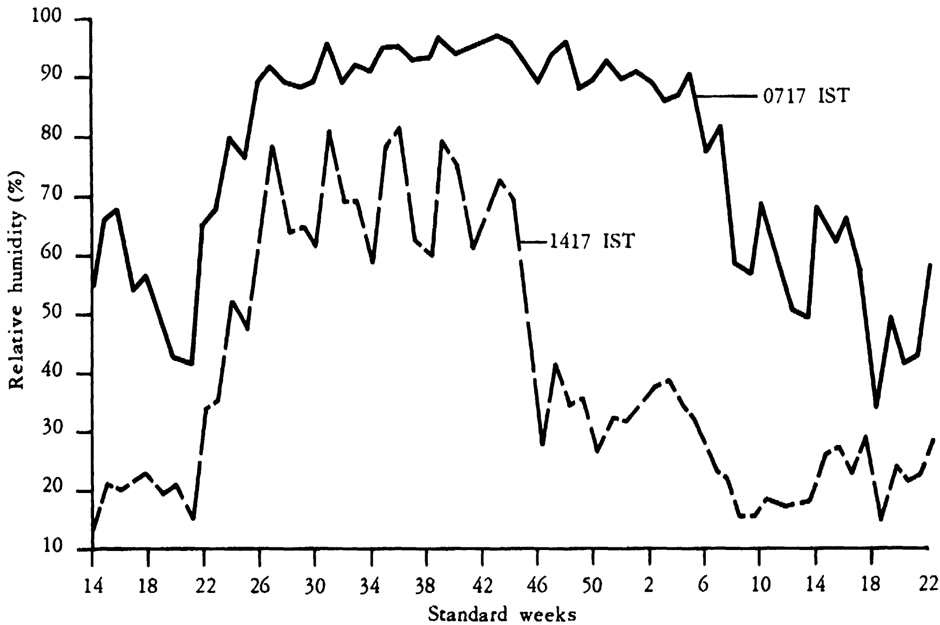



**Figure 9. Weekly average relative humidity, ICRISAT Center, 1975-1976.**

# THE CEREALS

## Sorghum *(Sorghum bicolor)*

## Pearl Millet
## *Pennisetum americanum* L.)

Sorghum and millet are the main cereal crops wn under the erratic climatic conditions of he SAT. The two crops occupy in excess of 70 illion hectares, and form the staple cereals for ny millions of people.

The quantum leaps seen in production of rice nd wheat, brought about by high-yielding varieties and research-based technology, have in o way been matched by sorghum and pearl nillet. Farm practices remain essentially as ey have been for thousands of years. A orldwide effort in breeding superior varieties s just now getting underway, and much mains to be learned about the role of cultural practices in increasing yields of these cereals in the SAT. The two cereals can play major roles in feeding the underfed of developing nations if the total benefits of the agricultural sciences can be brought to bear.

### ICRISAT Goals

Long-term benefits expected through ICRISAT's cereal programs include:

Consistent improvement in performance of sorghum and pearl millet over a wide range of environments throughout the SAT.

Genotypes that have higher yield potential than now found in cultivated varieties.

Improved resistance to insects, diseases, and other parasites.

Improved nutritional value, cooking quality, and palatability.

ICRISAT scientists are pursuing these goals at the Center near Patancheru in Andhra Pradesh and at a number of other locations throughout India and the world. They have established communications with cereals breeders throughout the SAT so that exchange and evaluation of genetic materials can be thoroughly accomplished, and so that all may share in progress and approaches to problems. The emphasis is always on cooperation with scientists working in national programs.

## ICRISAT Center

ICRISAT Center provides a wide range of environments for the development and testing of plant materials for the SAT. It has red and black soils and three growing-season environments. The rainy season, known locally as monsoon or kharif, occurs from June through September, and has long days until the September equinox. The post-rainy season, known locally as post-monsoon or rabi and occupying the months of October through January, has little rainfall and is cooler and days are shorter. Crops grown during the post-rainy season rely on residual soil moisture or on irrigation. From February until the rains begin in June is known as the hot dry season. Temperatures at flowering time are very high during this season, and short-season crops may be grown if irrigation is provided. Certain areas of the Center are saline and others have impeded drainage, making it possible to evaluate plant performance under a variety of conditions as they exist in many areas of the SAT.

# SORGHUM

the nitrogen produced more efficiently in producing grain.

Grain-quality improvement must be one of the pillars of the program. The move away from photoperiod sensitivity results in grain sometimes ripening under wet conditions. Resistance to grain mold, or protection from it, is therefore essential. ICRISAT's pathologists report progress both in the technology of inducing grain-mold attack and in the identification of resistant types. The Earliness with Grain Mold project records progress in breeding these resistances into cultivars, and in the perfection of large protective glumes. Basic knowledge of the characters which control good cooking quality (as esteemed by the housewife) is still lacking, but ICRISAT is developing cooperative arrangements with CFTRI (Central Food Technological Research Institute) and NIN (National Institute of Nutrition) to correct this deficiency. The high-lysine work has continued, but the process of combining this character with good cooking and flavor characteristics may be long.

One of the "way-out" projects, Grain-Grass Sorghums, has moved more rapidly towards immediate usefulness than had been expected. This very different plant type shows promise of unusual earliness, good ratoonability, good drought resistance and good levels of other resistances, combined with the photosynthetic efficiency of the small leaf and high plant populations which can be used with short more-slender plants. The Tetraploid Sorghum project records crosses with wild S. *halepensia* types to move some of the excellent adaptive characters of this group into the cultivated sorghums. The High Altitude project is in abeyance at present, in view of work in progress in Ethiopia and Mexico.

A total of 14 240 germplasm accessions are now available at ICRISAT Center; the collection is being screened for resistances to grain molds, other diseases, pests, *Striga*, and drought.

A departmental newsletter, "Semi-Arid Cereals," was initiated in order to develop and maintain improved contacts with cereals workers in the SAT.

# Germplasm

### Collection and Maintenance

The ICRISAT sorghum germplasm bank contains 14 240 accessions consisting of 11 778 lines covered by IS numbers and 2 462 accessions yet to be numbered by ICRISAT (Table 1). The identification of some of the IS numbers in the world collection was in doubt, so a second set was obtained from Purdue University, corresponding IS numbers were sown side by side, and checked. IS entries totaling 10 678 from Purdue were planted, but 1 100 did not germinate. Eight of the 9219 ICRISAT IS entries sown did not germinate. Photosensitive lines from the guinea, caudatum, and durra groups did not flower. Remnant seed, except for about 150 lines, was available in the store; this seed was transplanted to the nursery.

### New Collections

The important post-rainy season sorghum areas of Andhra Pradesh were visited and 147 farmers' types collected (Table 2). Four showing good quality grain were also found to contain shoot-fly resistance.

### Evaluation

A total of 14 029 accessions were evaluated for plant height, days to 50-percent flowering, awns, midrib color, pigmentation, tillering, peduncle exsertion, earhead length and breadth, panicle type, glume color and covering, grain color and 100-seed weight, threshability, luster, presence of subcoat, endosperm texture, and endosperm type.

### Screening for Insect, Disease, *Striga*, and Drought Resistance

The numbers of accessions screened are listed in Table 1.

### Documentation and Publishing of Evaluation

A pilot catalog with the 1974 post-rainy season data collected from 300 accessions was pre-

**Table 1 Sorghum germplasm accessions at ICRISAT Center, 31 May 1976.**

| | | |
|---|---|---|
| A) | Collections covered by IS numbers: | |
| 1. | AICSIP, Purdue sets | 11 753 |
| 2. | USDA (Washington) | 25 |
| | | 11 778 |
| B) | Collections not covered by IS numbers: | |
| 1. | NES. NSS numbers from USDA (Washington) | 187 |
| 2. | Ethiopian collection | 1 083 |
| 3. | Ethiopian Market collections (sent by C.J.P. Seegeler, Holland) | 52 |
| 4. | Nigerian collections | 24 |
| 5. | Yemen (brought by D.L.Oswalt) | 23 |
| *6. | Farmers' types from Andhra Pradesh | 147 |
| 7. | Farmers' types from North Ghana | 52 |
| 8. | Named cultivars | 349 |
| *9. | Named cultivars (recent collection) | 29 |
| 10. | Genetic-stock collection: | |
| i) | Quality lines | 6 |
| ii) | Insect-resistant lines | 122 |
| iii) | Disease-resistant lines | 47 |
| iv) | *Striga*-resistant lines | 14 |
| v) | Cytoplasmic A and B lines (93 × 2) | 186 |
| vi) | IS conversion lines | 127 |
| *vii) | Scented sorghums from Lucknow | 12 |
| viii) | Grass-grains | 2 |
| | | 2 462 |

Recently added, yet to be planted and multiplied

pared in conjunction with the Taximetric Laboratory of the University of Colorado. Data were tabulated for the remaining accessions and are being sent to Colorado for inclusion in the catalog.

### Seed Distribution

Requests from scientists in India and elsewhere for consignments of germplasm involving 2 954 samples were processed.

### Classification

The applicability of various classification systems was tested and the world collection is being classified according to Harlan's and de Wet's system. Panicle branches of all entries are being preserved as reference samples.

### Looking Ahead in Sorghum Germplasm

Now that rejuvenation of most IS numbers, as far as can be traced, has been completed, more attention can be paid to new collection efforts. Firstly, hilly and tribal areas in India will be searched. The post-rainy season cultivars are not well represented in the ICRISAT collection, and Andhra Pradesh has many forms to contribute. Use of hybrid sorghum is on the increase, and its adoption endangers conservation of local germplasm in some areas.

The proposals of the IBPGR (International Board for Plant Genetic Resources) Working Committee on Sorghum and Millets await publication. Priorities for collection abroad

**Table I**

| Screened for | No of accessions |
|---|---|
| Disease resistance | 5 188 |
| Insect resistance | 486 |
| Drought resistance | 50 |
| *Striga* resistance | 153 |
| General purposes | 800 |

Table 2. Sorghum accessions received at ICRISAT Center during 1975-1976.

| Country | Number | Description | Country | Number | Description |
|---|---|---|---|---|---|
| India | 7 | Farmers' types | India | 2 | Wild types |
| | 109 | Named cultivars | Yemen | 23 | Farmers' types |
| | 8 | Sweet sorghums | Nigeria | 8 | Farmers' types |
| | 12 | Scented sorghums | Turkey | 1 | Farmers' types |
| | 6 | *Striga* resistant | Sudan | 1 | *Striga* resistant |
| | 3 | Midge resistant | United Kingdom | 1 | *Striga* resistant |

include Mali, Sudan, Niger, Chad, Central African Republic, Tanzania, Malawi, Somalia, Botswana, Zambia, Mozambique, southeastern Asia, China, Turkey, northern Syria, Yemen, and Saudi Arabia.

Efforts to introgress wild sorghum germplasm (wild species are available, but in insufficient numbers) into the cultivated sorghum for various purposes will continue.

# Breeding

## Yield

**The improvement of composite populations by recurrent selection.** This improvement program is divided into three projects: (i) Source, the creation and shaping of new composite populations; (ii) Backup, the slow improvement of populations aiming to conserve much of the useful genetic variability; (iii) Advanced, in which the prime objective is rapid progress to achieve material immediately useful to national programs and to farmers.

**Source populations.** Five populations are being developed.

**Backup populations.** There are seven populations in this group. We are using half-sib testing at two or three locations in India, followed by recombination in a cycle of two generations each year. A total of 6241 half-sibs were tested; 1737 were selected for recombination from all these seven populations during the year.

**Advanced populations.** The eight populations in this group are being improved by $S_1$ or $S_2$ testing; testing across locations was not possible this year, but testing at two fertility levels at ICRISAT Center was accomplished. The populations are Fast Lane/R, Fast Lane/B, US/B, US/R, RS/R, RS/B, Serere elite, and Tropical conversion.

(1) Fast Lane/R and (2) Fast Lane/B populations: The best ten $S_1$ lines of each population selected in post-rainy season 1974 were diallel crossed in hot dry season 1975, and a second random mating was made in rainy season 1975. About 800 male-sterile heads were chosen from each population and evaluated for qualitative characters in half-sib rows during post-rainy season 1975. About 50 percent were selected for $S_1$ testing in rainy season 1976. Selected lines taken from the first cycle of $S_1$ testing (post-rainy season 1974) were evaluated in yield trials in rainy season 1975 at two fertility levels (168 selections), and 120 $S_3$ lines were similarly tested in post-rainy season 1975 (Table 3). Several entries performed well under low-fertility levels, and a useful proportion showed yield levels similar to those of the AICSIP (All India Coordinated Sorghum Improvement Project) controls.

(3) US/B and (4) US/R populations: The first cycle of $S_1$ selection was completed in 1974. In 1975, 800 half-sibs from US/B and 825 half-sibs

'able 3. **Grain yields of promising fast-lane $S_2$ lines (rainy season 1975) and $S_3$ lines (post-rainy season 1975).**

| | Rainy season | | | Post-rainy season |
|---|---|---|---|---|
| | High fertility, black soil[a] | Low fertility, red soil[b] | Mean | High fertility red soil[a] |
| | (kg/ha) | (kg/ha) | (kg/ha) | (kg/ha) |
| B 11 | 5 960 | 4 270 | 5 120 | — |
| R 53 | 6 580 | 3 020 | 4 800 | — |
| R 274 | 5 680 | 3 180 | 4 430 | — |
| R 139 | 5 540 | 2 700 | 4 130 | — |
| B 104 | 5 700 | 2 510 | 4 100 | — |
| R 141 | 4 960 | 2 960 | 3 960 | — |
| R 100 | 5 890 | 1 950 | 3 920 | — |
| R 147 | 4 700 | 2 740 | 3 720 | — |
| CSH-1[c] | 5 220 | 3 140 | 4 180 | 6 130 |
| 370[d] | 5 740 | 2 050 | 4 000 | — |
| 148[d] | 1 570 | 2 080 | 1 820 | — |
| R 16[d] | — | — | — | 2 540 |
| B 20 | — | — | — | 6 150 |
| R 152 | — | — | — | 5 870 |
| B 117 | — | — | — | 5 730 |
| B 100 | — | — | — | 5 560 |
| R 274 | — | — | — | 5 530 |
| R 139 | — | — | — | 5 480 |
| R 274 | — | — | — | 5 410 |
| LSD | 1 600 | 940 | 1 260 | 1 370 |
| CV | 18.2% | 19.5% | 25.9% | 15.0% |

a High-fertility treatment (received 111 kg N, 46.5 kg P/ha)

b Low-fertility treatment (received 20 kg N, 9 kg P/ha)

c Hybrid Check

d Variety Check

rom US/R were grown in the rainy season. Of hese, 359 and 433 were selected respectively; lines from them were planted at ICRISAT Center and at Bhavanisagar (Tamil Nadu). Of these, 194 lines were selected from each population. Trials of these $S_2$ lines have been dispatched to three locations in India, four locations in West Africa, and one in East Africa.

(5) RS/R, (6) RS/B, (7) Serere elite, and (8) Tropical conversion: Three cycles of mass selection for photoperiod insensitivity and grain quality were completed. The first $S_1$ testing cycle was initiated in post-rainy season 1974. A total of 1 946 $S_1$ lines from each of these populations were tested in rainy season 1975, but stands in the trials were poor.

New populations are required to meet the requirements of differing rainfall belts across Africa north of the equator, post-rainy season conditions in India, and the bird areas of Africa where brown grains have to be grown. These are to be assembled from good lines in our existing populations, so some 2 000 $S_2$ lines were evaluated at ICRISAT Center and at Bhavanisagar. The best of these have been sent for testing to locations in West Africa, East Africa, and India.

**Stability and adaptability of the populations.** A trial of 144 entries consisting of 16 representative lines from each of 9 populations was conducted at 9 locations in the SAT. Yield data (Table 4) were received from several locations. Mean yields of the photoinsensitive populations (averaged over 16 lines) at each location, along with stability parameters are presented in Table 4. Serere elite, High Altitude, US/B, and RS/B populations had a high mean value, and a higher $b_i$ value than unity, indicating that these populations can respond to improved environments. Tropical conversion performed reasonably well under poor environments, but could not take advantage of better conditions. Performance of some of the high-yielding lines is listed in Table 5.

*ICRISAT's breeding plots are visited by plant scientists from all over the world.*

**Table 4. Mean grain yield of populations at different locations and stability parameters ($x_i$, $b_i$, and $S^2d_i$).**

| Population | LOCATION | | | | | | | Stability parameters[a] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dharwar | Indore | ICRISAT (high fertility)[b] | ICRISAT (low fertility) | Akola | Khon Kaen | Serere | $x_i$ | $b_i$ | $S^2d_i$ |
| | (kg/ha) | | | | | | | ($\times 10^2$) | | ($\times 10^4$) |
| RS/R | 4 540 | 1 620 | 5 110 | 2 150 | 1 250 | 3 290 | 1 490 | 27.8 | 1.00 | −3.21 |
| RS/B | 4 760 | 1 610 | 5 000 | 1 680 | 1 150 | 3 370 | 1 720 | 27.6 | 1.02 | 1.98 |
| Serere elite | 5 200 | 1 780 | 5 420 | 2 000 | 1 260 | 3 540 | 1 730 | 29.9 | 1.11 | 0.13 |
| High altitude | 5 020 | 1 730 | 5 240 | 2 250 | 1 100 | 3 240 | 1 470 | 28.6 | 1.08 | −0.80 |
| Tropical conversion | 3 480 | 1 370 | 4 400 | 2 440 | 1 010 | 2 900 | 1 720 | 24.7 | 0.76 | 5.84* |
| US/R | 4 360 | 1 300 | 5 020 | 2 290 | 1 150 | 3 170 | 1 430 | 26.7 | 0.99 | −1.17 |
| US/B | 4 350 | 1 740 | 5 450 | 2 080 | 1 190 | 3 380 | 1 520 | 28.2 | 1.03 | −0.19 |

*Significantly different from unity at 5% level of significance

[a] Eberhart & Russel, Crop Sci., 6, 1966, 37-40

[b] High fertility received 111 kg N, 46.5 kg P/ha; low fertility received 20 kg N, 9 kg P/ha.

**Table 5. Grain yield of some of the high-yielding lines (rainy season 1975) drawn from ICRISAT advanced populations at seven locations.**

| Entry No. | Pedigree | Dharwar | Indore | ICRISAT (high fertility)[a] | ICRISAT low fertility) | Akola | Khon Kaen | Serere | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | | (kg/ha) | | | | | | | |
| 45 | Serere elite | 6740 | 1970 | 6670 | 2210 | 1970 | 4080 | 7140 | 4500 |
| 44 | Serere elite | 5810 | 1760 | 6550 | 3010 | 960 | 3740 | 7420 | 4320 |
| 100 | US/R | 6240 | 2340 | 7200 | 2290 | 1090 | 4050 | 6110 | 4190 |
| 7 | RS/R | 6930 | 220 | 6470 | 2040 | 1180 | 4230 | 8210 | 4180 |
| 46 | Serere elite | 6240 | 2130 | 6260 | 3050 | 1720 | 4200 | 5000 | 4090 |
| 30 | RS/B | 6390 | 2300 | 2410 | 5540 | 1330 | 3580 | 6940 | 4070 |
| 86 | US/R | 5210 | 2380 | 5300 | 3680 | 1610 | 3370 | 6710 | 4040 |
| 62 | High altitude | 6880 | 1660 | 7910 | 1560 | 1480 | 3500 | 5200 | 4030 |
| 58 | High altitude | 6670 | 2290 | 5570 | 1370 | 1140 | 3010 | 7980 | 4000 |
| 109 | US/B | 4650 | 1620 | 6770 | 1920 | 1660 | 4660 | 6590 | 3980 |
| 34 | Serere elite | 5630 | 1760 | 5730 | 2530 | 1400 | 3190 | 7540 | 3970 |
| 33 | Serere elite | 4500 | 2020 | 6120 | 3920 | 1590 | 3440 | 5910 | 3930 |
| 20 | RS/B | 7010 | 1400 | 4780 | 1440 | 1770 | 3670 | 7420 | 3930 |
| 50 | High altitude | 5750 | 2200 | 6570 | 2690 | 1290 | 3500 | 5400 | 3910 |
| 1 | RS/R | 5760 | 1740 | 5710 | 1760 | 1720 | 3840 | 6890 | 3880 |
| 102 | US/B | 5280 | 2600 | 7390 | 3490 | 1540 | 3740 | 4720 | 3820 |
| 41 | Serere elite | 5680 | 2040 | 5630 | 2090 | 1000 | 3880 | 6350 | 3810 |
| 63 | High altitude | 5690 | 2860 | 5560 | 1880 | 960 | 3290 | 6230 | 3780 |
| 23 | RS/B | 3960 | 2040 | 5700 | 1730 | 1210 | 3470 | 8330 | 3780 |
| 70 | Tropical conversion | 4720 | 1540 | 6570 | 3320 | 1580 | 3440 | 5240 | 3770 |
| | Mean | 4500 | 1590 | 5120 | 2150 | 1170 | 3270 | 5160 | 3280 |

[a] High fertility received 111 kg N 46.5 kg P/ha, low fertility received 20 kg N, 9 kg P/ha

## Pest Resistance

Breeding has so far been concentrated on resistance to shoot fly. Several approaches are being used.

**Pedigree breeding.** Pedigree breeding is being used to incorporate resistances into adapted varieties of good agronomic type and grain quality and 26 such varieties (originating from India, West Africa, and East Africa) were crossed to resistant parents in post-rainy season 1975; 470 crosses for shoot-fly resistance, [illegible]3 for stem-borer resistance, and 466 for midge resistance were made.

**Pest-resistance populations.** Recurrent selection seems to be the best long-term approach for combining pest resistance with yield and grain quality. In post-rainy season 1975 we began to build a pest-resistance population by pollinating resistant lines with lines selected from the advanced populations. The selected lines carry high yield, good grain quality, and either the $ms_3$ or $ms_7$ gene. During the season, 375 crosses for shoot-fly resistance, 115 for stem-borer resistance, and 285 for midge resistance were made.

**Sidecars to advanced populations.** Most of the advanced populations have a low level of pest resistance. Consequently, seven shoot-fly-resistance lines (EN 3255, EN 3257, EN 3309, EN 3332, EN 3337, EN 3342, and EN 3363), one stem-borer-resistant line (E303), and three midge-resistant lines (IS 2501C, IS 2597C, and IS 2816C), all of reasonable agronomic type, were crossed on to five advanced populations. By making one or two backcrosses (the sidecar approach), these resistances will be transferred to the advanced populations.

**Genetic studies.** One small study was done to determine which generation is best to select for resistance. Parents, half-sibs, $S_1$, and $S_2$ lines were grown from WABC × EN and Bulk Y × EN crosses. The proportion of selected lines is given in Table 6.

These very preliminary results suggest that resistant genotypes can be successfully identified in $S_1$, progeny testing.

**Table 6. Percentage of pest resistance lines selected from different generations.**

| | Selections | |
|---|---|---|
| | very promising | promising |
| | (%) | (%) |
| Half-sib | 0 | 10 |
| $S_1$ | 10 | 2 |
| $S_2$ | 12 | 6 |

## *Striga* Resistance

The laboratory seedling-screening technique to identify low-strigol-producing sorghums were perfected. Such resistance must be confirmed by field testing; and Punjabrao Krishi Vidyapeeth (agricultural university) at Akola, Maharashtra, has agreed to provide this facility. *Striga asiatica*, *S. densiflora*, and *S. euphrasioides* all parasitize sorghum in India, and suitable testing sites are being sought.

**The breeding program.** A *Striga hermonthica*-resistance composite received from Samaru has been random-mated twice at ICRISAT Center; 120 crosses were made with international nursery and other adapted lines to incorporate photoperiod insensitivity.

We obtained from Africa and India 42 lines reported to have differing types of resistance mechanisms, such as Dobbs, Framida, CSV-5, and 206; intercrosses were made between them in post-rainy season 1975.

A ıeplicated trial of 200 entries from the germplasm collection, from farmers' types, and from the *Striga* composite was planted under natural infestation conditions at ICRISAT Center in post-rainy season 1975. *Striga* incidence was patchy and only 59 lines could be selected for further screening.

A synthetic strigol analog from Sussex University was evaluated in boxed soil and in field plots. Box experiments were done in rainy season 1975, using red and black soils. Applications of 1, 5, and 10 ppm of strigol were made following 21 or 27 days of pretreatment. Susceptible sorghum (cv CSH-1) was planted one month later on 11 and 18 August. *Striga* counts were taken three times, and subterranean *Striga* was also counted at the end of the experiment. There were no treatment differences on the black soil. Data from the red-soil test are presented in Table 7. A similar experiment conducted on black soil under field conditions in post-rainy season 1975 showed no treatment differences, possibly because the strigol analog is unstable under alkaline conditions.

**Table 7. *Striga* count in boxed red soil receiving three levels of synthetic strigol analog.**

| Treatment | mean number *Striga* plants |
|---|---|
| | (no) |
| 1 ppm | 40.0 |
| 5 ppm | 11.3 |
| 10 ppm | 28.7 |
| Control | 72.0 |
| L.S.D. (P = 0.05) | 25.5 |
| CV | 24% |

Twenty lines from Samaru, Nigeria, which had undergone four stages of screening against *Striga hermonthica* were received. *Striga densiflora* and *S. asiatica* seeds from Mohol and Bhavanisagar, respectively, were added to our collection.

Young roots of resistant and susceptible varieties of sorghum are being sectioned to identify anatomical features which may be associated with mechanical resistance to *Striga* infestation.

## International Testing of Breeding Material

**International trials.** In 1975, four trials were sent to various locations in Africa, India, Southeastern Asia, and South America. Data have not been returned from all of the sites.

Trial 1 contained 49 entries of material from the AICSIP and ALAD (Arid Lands Agricultural Development program), along with some good world collection and EC (exotic collection) entries, together with some ICRISAT lines and a space for a local check. This went to 14 locations.

Trial 2 consisted of lines taken from our populations and has been reported under population improvement. It was sent to 14 locations.

Trial 3 contained 48 entries of Serere (Uganda) material (plus local check) and was sent to nine locations within 10° latitude of the equator.

Trial 4 contained 24 lines and a check; it was a reduced version of Trial 1 for locations which could only handle smaller trials. This trial was sent to 19 locations.

In addition, two of the AICSIP trials were sent to a few selected locations.

The AICSIP material (CSH, CSV, SPH, SPV) did well in many places (Table 8). Material from Serere in Uganda (3DX, 5DX, 6DX, 9DX, 14-P, and Kafinam crosses) also did well in the equatorial belt.

**Trials at ICRISAT Center.** A range of material from all our projects was tested on low-fertility red soil (20 kg N, 9 kg P/ha applied) and on high-fertility black soil (111 kg N, 46.5 kg P/ha) in rainy season 1975, and on high-fertility black soil (111 kg N, 46.5 kg P/ha) applied in post-rainy season 1975. Replications were also tested under heavy shoot-fly attack. In the rainy season, there were ten trials containing 2205 entries, of which 133 were carried forward for further trial. In the post-rainy season, there were 11 trials containing 1532 entries Performance of a few are presented in Table 9 Selecting under the contrasting conditions of rainy and post-rainy seasons should help to identify types with broad adaptation.

Table 8. **Grain yields of certain entries in international sorghum trials.**

(A)

| Pedigree | Feni, Bangladesh | Serere Uganda | Yei Sudan | Yousafwalla, Pakistan | Laguna Philippines |
|---|---|---|---|---|---|
| | (kg/ha) | | | | |
| Kafinam × Lulu | 2 700 | 4 000 | 2 700 | 2 700 | 1 200 |
| Kafinam × SB 65 | — | 3 600 | 2 800 | — | 3 500 |
| Kafinam × Simila | 3 600 | 3 100 | 3 200 | 2 600 | 3 700 |
| IS 858 | 3 000 | 3 000 | 1 400 | 1 700 | — |
| 14-P-3-2-1 | — | 2 900 | 1 300 | — | 3 500 |
| CSH 1 | 2 600 | 2 000 | 1 400 | 3 500 | — |
| CSH 5 | 1 300 | 1 600 | 1 100 | 5 700 | 1 300 |
| CSH 6 | 2 100 | 1 600 | 2 700 | 5 200 | — |
| CSV 3 | 800 | 2 300 | 600 | 3 200 | 300 |
| CSV 4 | 500 | 2 100 | 1 700 | 1 200 | 600 |
| CSV 6 | 600 | 1 400 | 900 | 2 400 | — |
| Local check | 2 400 | 2 100 | 2 000 | 2 200 | 2 400 |

(B)

| Pedigree | Bambey Senegal | Saria, Upper Volta |
|---|---|---|
| | (kg/ha) | |
| CSV 1 | 2 000 | 4 100 |
| CSV 2 | 2 200 | 2 800 |
| CSV 4 | 2 300 | 4 100 |
| CSV 5 | 2 000 | 4 600 |
| SPV 9 | 1 300 | 4 700 |
| SPV 13 | 1 400 | 4 500 |
| SPV 35 | 2 000 | 4 700 |
| SPV 58 | 3 000 | 3 100 |
| CSH-1 | 3 700 | 4 300 |
| CSH 5 | 1 200 | 6 400 |
| Local check | 4 000 | 4 300 |

(C)

| Pedigree | Bambey Senegal | Saria Upper Volta |
|---|---|---|
| | (kg/ha) | |
| CSH 5 | 2 300 | 5 800 |
| CSH 6 | 4 500 | 6 500 |
| SPH 1 | 3 500 | 5 200 |
| SPH 2 | 3 500 | 4 600 |
| SPH 4 | 2 900 | 5 500 |
| SPH 6 | 3 500 | 4 600 |
| SPH 10 | 4 100 | 5 900 |
| SPH 21 | 1 500 | 5 400 |
| SPH 24 | 3 400 | 5 700 |
| MSH 31 | 2 300 | 5 300 |
| 22F | 4 000 | 5 100 |
| Local check | 4 300 | 4 000 |

*Continued*

Table 8 *continued*

(D)

| Pedigree | Khon Kaen, Thailand | Farm Suwam, Thailand | Laguna, Philippines |
|---|---|---|---|
| | (kg/ha) | | |
| Serena | 4700 | 3800 | 1800 |
| Dobbs | 2700 | 2800 | 3600 |
| 3DX 57/14/4 | 4600 | 3900 | 2100 |
| 5DX 36/ 1/2 | 3400 | 2400 | 3000 |
| 5DX 61/ 6/2 | 4300 | 3000 | 2100 |
| 5DX 136/1/2/1 | 3400 | 3000 | 2300 |
| 5DX 142/4 | 4100 | 3200 | 1100 |
| 6DX 2/2/4 | 3700 | 3400 | 2300 |
| 9DX 2/3/2 | 4500 | 3600 | 1700 |
| 9DX 6/$F_5$/30 | 4200 | 3000 | 1000 |
| 9DX 9/$F_5$/11 | 3900 | 3200 | 600 |
| Local check | 2900 | 2700 | 2000 |

## Quality

### Earliness with Mold Resistance

Earliness and non-weathering lustrous grains resistant to grain molds such as *Curvularia, Fusarium, Phoma,* etc., were the main selection criteria. A crossing program bringing in different component characters through several parents of diverse origin was undertaken. The following parents were used in these crosses:

Early (40 to 50 days to flower): 12 IS conversion lines from Puerto Rico, 18 IS numbers from the world collection.

Mold-tolerant: 23 Zera Zeras, CS 3541, 8272-1, M-35-1, IS 9333, 9327, and 9530.

High-yielding: 12 from India, 2 from West Africa, 3 from East Africa, 3 from Egypt, and 3 elite entries from ICRISAT trials.

A total of 2250 single crosses, 341 double crosses, and 175 three-way crosses were made. Most of the $F_1$ hybrids were grown in the post-rainy season and 60 percent were rejected. All the single crosses and double crosses were used as pollen parents on early good-grain male steriles ($ms_3$ and $ms_7$) in adapted backgrounds, and from this a composite population will be developed. Some 130 single-cross $F_2$'s were planted in the hot dry season nursery, but selection was limited to earliness, good-grain quality, and important agronomic characters, as no grain molds developed.

Two generations of selfing and selection in random-mating populations and in segregating crosses between populations and elite varieties resulted in 454 good-grain early types (40 to 50 days to flower) being selected in rainy season 1975. These were grown in the post-rainy season, and 235 were selected for yield trials in rainy season 1976. Very-early lines were crossed to several late lines having high seed weight and hard lustrous large grains. Selection for photoinsensitivity, earliness, and good-grain quality in the $F_2$ and $F_3$ generations resulted in

| Pedigree | Time to flower (rainy season) | Plant height | Yield: Rainy, high-fertility[a] black | Yield: Rainy, low-fertility[b] red | Yield: Post-rainy high-fertility black | Yield: Mean | 100-seed weight | Shootfly (dead hearts) |
|---|---|---|---|---|---|---|---|---|
| | (day) | (cm) | (kg/ha) | (kg/ha) | (kg/ha) | (kg/ha) | (g) | (%) |
| Diallel 918 × PP3 | 64 | 200 | 6 600 | 1 400 | 8 000 | 5 300 | 2.46 | 55 |
| Diallel 7469 | 71 | 205 | 5 500 | 3 400 | 6 300 | 5 100 | 2.80 | 50 |
| Bulk Y × EC 64376 | 64 | 200 | 5 300 | 2 300 | 7 300 | 5 000 | 2.73 | 25 |
| Indian × exotic 8465 | 65 | 195 | 6 500 | 1 600 | 6 800 | 5 000 | 3.13 | 54 |
| Pickett-4-8 | 66 | 180 | 6 300 | 1 800 | 5 300 | 4 500 | 2.69 | 69 |
| W. African × Nigerian | 64 | 190 | 4 700 | 900 | 7 200 | 4 300 | 2.80 | 44 |
| Diallel 1008 | 69 | 165 | 3 300 | 2 400 | 7 200 | 4 300 | 2.18 | 25 |
| Diallel 15683 | 70 | 205 | 5 800 | 2 400 | 4 300 | 4 200 | — | 33 |
| EN 3355 | 61 | 185 | 5 400 | 2 100 | 4 900 | 4 100 | — | 29 |
| PP6 | 57 | 150 | 4 500 | 1 400 | 6 200 | 4 000 | — | 20 |
| Pickett-3 | 69 | 153 | 4 600 | 2 200 | 4 500 | 3 800 | 2.25 | 39 |
| Diallel 1031 | 57 | 165 | 5 500 | 1 300 | 4 600 | 3 800 | 2.70 | 39 |
| Diallel 848 | 59 | 165 | 5 100 | 1 000 | 5 300 | 3 800 | — | 30 |
| Diallel 910 | 64 | 160 | 4 700 | 1 100 | 4 800 | 3 500 | 2.42 | 21 |
| Bulk Y × Pickett-4-8 | 64 | 130 | 3 100 | 1 900 | 4 900 | 3 300 | 3.49 | 50 |
| CSV-3 (370)[c] | 64 | 170 | 6 300 | 3 000 | 3 600 | 4 300 | 2.20 | 57 |
| CSH-1[d] | 60 | 170 | 6 800 | 4 000 | 9 300 | 6 700 | 2.72 | 44 |

[a] High-fertility plots received 111 kg N 46.5 kg P/ha

[b] Low-fertility plots received 20 kg N, 9 kg P/ha

[c] Control variety

[d] Control hybrid

135 early lines with large corneous lustrous grains.

The mold-resistance composite from Nigeria was random mated and 426 good steriles selected.

### Large Glumes

The value of this character in giving protection from weathering is being tested by transferring large glumes to early photoinsensitive backgrounds and testing the resultant early large-glume types in the rainy season, both under natural and artificial mold environments. Some 286 single crosses, 26 double crosses and 25 $F_2$ hybrids were grown in rainy season 1975 and 170 early and large-glume selections were taken. The $F_3$ generation was planted in the following post-rainy season and 100 lines were selected for grain-mold and yield testing in rainy season 1976. Other $F_2$'s were grown in the summer nursery, and 450 early plants with large glumes were selected for similar testing.

Genetic male sterility has been incorporated in the large-glume parents by crossing them to early male-steriles ($ms_3$ and $ms_7$). Early large-glume male-steriles segregating in the $F_2$'s have been sibbed with early large-glume fertiles. A population with a high level of outcrossing (large glumes limit the level of outcrossing) is thus being composited, and the glume coverage of the grain will be improved through recurrent mass selection.

### Grain Quality Improvement

**Evident quality.** A population composed of sorghums with good evident grain quality is being developed, assessment being made for color, plumpness, luster, proportion of corneous endosperm, and hardness. The population is being assembled on a full-sib system. The $F_1$'s of the crosses and the pollinators are being assessed for yield in alternate generations. Yield trials of 161 pollinators and 73 crosses were planted in rainy season 1976.

Crosses were made to initiate sidecars for large grain, local high-quality grain, and high-lysine grain. Sixteen samples of 2 kg each of a range of high-quality types were taken to CFTRI for preliminary assessment of the quality requirements for sorghum as a food. RY 49, an Ethiopia cultivar with a wheat-like flavor, and the medium-lysine mutant P721 were included. Twelve sorghums were received from Lucknow; this group may contain types with a grain scent similar to that of Basmati in rice. Cv RY 49 is being converted to photoperiod insensitivity with reduced plant height.

**Nutritional quality.** Plantings in rainy season 1975 contained 137 photoinsensitive high-lysine selections from the original Purdue crosses, 113 selections from plump opaque intercrosses, 693 selections from crosses of Serere Populations × Ethiopian *hl*, and 190 newly received selections from Purdue University in Indiana, USA. Head rows of P721 were also grown, and showed some pollen sterility. Some 3 000 selections were analyzed for protein and DBC (dye-binding capacity) values.

Three groups of the selections are being combined into populations. Group A, with very high DBC values per 80 mg of protein (39+), contained selections from seven lines. Group B (DBC values of 30 to 38.5), contained selections from 28 lines. Group C, consisting of the modal DBC values 28 to 29.5, contained selections from 25 lines. P721 selections were added to each of these groups; within-group intercrossing, using the segregating male-steriles, was begun at Bhavanisagar in the summer. In post-rainy season 1975, selections from the same rainy season planting were grown as four groups—high DBC, low protein (25 lines); high DBC, high protein (8 lines); low DBC, low protein (6 lines); and low DBC, high protein (16 lines).

Laboratory analyses are not yet available for most of this material, but sufficient data are in to show that season-to-season fluctuations in protein levels may be large (Table II).

Similar results were obtained from the rainy season 1975 selections, many of which had been chosen for the low-protein high DBC group in post-rainy season 1974, but showed high protein with reduced lysine in rainy season 1975. The differences are large and too

**Table II**

| | Post-rainy season 1974 | | | Rainy season 1975 | | | Post-rainy season 1975 | | |
|---|---|---|---|---|---|---|---|---|---|
| Entry | Protein | DBC[a] | | Protein | DBC | | Protein | DBC | |
| | (%) | | (no)[b] | (%) | | (no) | (%) | | (no) |
| 79337-2 | 7.2 | 30.0 | 1 | 7.8 | 34 | 1 | 12.0 | 24.5 | 20 |
| 79339-3 | 7.1 | 30.5 | 1 | 7.9 | 28 | 1 | 13.5 | 24.5 | 6 |
| 79337-4 | 7.2 | 31.5 | 1 | 7.2 | 28 | 1 | 12.7 | 23 | 8 |
| 79751-4 | 7.6 | 30.0 | 1 | 7.8 | 30 | 1 | 15.1 | 25.5 | 6 |
| 79337-2 | 7.2 | 30.0 | 1 | 7.0 | 32 | 1 | 13.6 | 23.5 | 6 |
| 79339-3 | 7.1 | 30.5 | 1 | 7.5 | 31.5 | 1 | 12.0 | 23.0 | 4 |

[a] Per 80 mg protein

[b] Number of entries used to calculate the mean

*Study of the role of cereals in intercropping was a major activity during the year.*

**Table III**

| | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| | (no) | (no) | (no) | (no) | (no) | (no) |
| Bhavanisagar (hot dry season 1976) | 580 | 525 | 68 | — | — | 1 173 |
| ICRISAT Center (rainy season 1975) | 97 | 328 | 389 | 146 | 14 | 974 |

consistent to be simply due to error. It is possible that the *hl* gene is a prolamine suppressor which breaks down or loses penetrance, or mutates back to normal rather steadily when in the normal endosperm background.

## Long-Term Projects

### Grain-Grass Sorghums

Grain-grass sorghums may be valuable in difficult or irregular rainfall areas. They are drought resistant, ratoon well, and mature in 70 to 75 days. Their maturity length is not much affected by cold, so they may also be valuable for post-rainy season planting.

Many crosses were made between grain-grass and normal sorghums showing resistance to pests and diseases, good grain quality, and good yield. $F_1$'s were grown in Coimbatore during hot dry season 1975. These were intercrossed, backcrossed to new grain-grass lines obtained from Purdue University and Texas A and M University, and selfed. In the $F_2$ material, very good segregants resembling the grain-grass parents with improved plant type and excellent grain quality appeared. Double and backcrosses have been used to pollinate genetic steriles to develop a random-mating population.

A second series of crosses was made between adapted pest- and disease-resistant normal lines and grain-grass lines received from Purdue and planted in the post-rainy season in late 1974. $F_1$'s were grown in rainy season 1975 and $F_2$'s were also crossed on to steriles.

In post-rainy season 1975, cold night temperatures had little effect on flowering date or growth of the grain-grass material, but favored profuse tillering. We selected 1 173 early plants and grew them at Bhavanisagar in hot dry season 1976. A second series of selections was made 2 weeks later, and those were grouped into five classes—Class I, big grassy types, and Class V, normal cultivated sorghum, with classes II, III, and IV intermediate. The number of selections falling into each class are listed in Table III.

Some 380 families were selected as $F_4$-derived lines at Bhavanisagar and outstanding individual plant selections were made.

Five grain-grass lines were tested for drought resistance in post-rainy season 1975. Some showed good drought avoidance or excellent recovery.

### Tetraploid Grain Sorghum

Crosses made between photosensitive Serere tetraploid bulks and photoinsensitive Ross 4N from the University of Nebraska gave good segregants in $F_2$. Selections were planted in rainy season 1975, and the range in days to flowering was 61 to 86.

Selections were made for the evident grain-quality characters of large grain, white color, thin pericarp, and corneous endosperm. These were planted on two dates in rainy season 1975. They showed only slight photoperiod sensitivity, and 120 further selections were taken. Selections were also made for these yield components—number of branches, number of nodes, and number of grains per branch. R

N selections exhibited a wide range of varia- ›ility in flowering date, height, and head haracters; 232 individual plant selections vere made. Eleven short fertiles and 52 photo- nsensitive steriles were chosen as good ources of $ms_3$ genetic sterility at the tetraploid evel.

In order to introduce *Sorghum halepense* ermplasm into the tetraploids, 110 crosses vere made with a type from Pantnagar and 86 rosses with another from Bangkok. $F_1$'s, lanted in post-rainy season 1975, resembled he wild parents. One backcross was made to n improved cultivated tetraploid.

Some tetraploid plants reverted back to the iploid, and these polyhaploids are being used › transfer *Sorghum almum* genes into good dapted diploids; 450 such crosses were made.

The good-grain-quality diploids 148, 22F, 219B, SC 423 74R 24/1-52, 74R 24/1-7, and 4R 23 (2-50) were successfully made into utotetraploid with colchicine.

## Physiology

›ur groups of physiological attributes must ›erate in an appropriate balance to provide e best possible adaptation for growth and nsistent yield. These relate to (i) high rate of oduction of dry matter per unit area per unit roduction resource and efficient distribu- of carbohydrate; (ii) production of high numbers per unit area and high grain- g rate; (iii) nutrient uptake and distribution upport the superior carbohydrate supply distribution in (i) and (ii) above, and (iv) ty to endure drought stress [i.e. the ability l the attributes in (i), (ii), and (iii) above to ribute efficiently towards yield production r water stress]. For each of these attri- s there is a wide range in genetic variability genotype × environment interaction. We attempted to assess some of this variabil- n relation to yield and to understand the ciations which exist between attributes, the aim of identifying source materials superior carbohydrate source and/or sink attributes, superior nitrogen uptake and distribution, and superior drought resistance, and utilizing them for genetic improvement.

### Variability in Growth Stages $GS_1$, $GS_2$, and $GS_3$

A variability study on attributes in $GS_1$ (vegetative phase), $GS_2$ (head development phase), and $GS_3$ (grain filling phase) of 49 genotypes is reported in Table 10. The position (from the top) varied from 2.0 to 5.8 (mean of 3.5), corresponding to a variability of 0 to 6.3 (2.6) leaf positions between the position of the largest leaf and the leaf expanded at the time of panicle initiation, i.e. the node bearing the largest leaf was, on the average, 2.6 nodes above the node which had a fully expanded leaf at panicle initiation.

Analysis of data on leaf area, leaf position, seed number, and grain filling involving 76 genotypes from another experiment has shown that the position of the largest leaf and its area was related to seed number per head and rate of filling of individual grains. Highest seed number per head within the maturity class 110 to 120 days was achieved when the position of the largest leaf was in the range of 3 to 6 from the top. To obtain about 1 000 seeds per head at population of 10 plants/$m^2$, the leaf area of the largest leaf had to be about 200 $cm^2$; for 2 000 seeds per head or more, the largest leaf had to be about 400 $cm^2$ or larger. Generally, the larger the area of the largest leaf, the larger was the total area of those leaves above the largest leaf, thus contributing to a rapid rate of grain filling. The position of the largest leaf was related to the total number of leaves, and the range 3 to 6 corresponded to total leaf number range of 12 to 16.

### Nitrogen Uptake and Distribution

Forty entries from elite selections were studied to define the range in variability in nitrogen uptake and distribution, and the possible influences on yield. The absolute amount of nitrogen in the grain at anthesis is only a small proportion of the total plant nitrogen, while under medium fertility levels the amount in the

**Table 10. Variability study on attributes in $GS_1$, $GS_2$, and $GS_3$ of 49 sorghum genotypes.**

| | | |
|---|---|---|
| | $GS_1$ | |
| | Mean | Range |
| Duration (days) | 32.8 | 30 - 41 |
| Leaves (no) | 9.4 | 8.3 - 10.2 |
| Leaf production (days/leaf) | 3.3 | 3.0 - 4.6 |
| | $GS_2$ | |
| | Mean | Range |
| Duration (days) | 42.5 | 31 - 64 |
| Leaves (no) | 6.2 | 2.2 - 10.8 |
| Leaf production (days/leaf) | 5.0 | 4.6 - 14.3 |
| | $GS_3$ | |
| | Mean | Range |
| Duration (days) | 47.2 | 31 - 56 |
| Grain yield (kg/ha) | 5440 | 2560 - 9940 |
| Yield (kg/ha per day per season) | 44.3 | 20.6 - 72.9 |
| Yield (kg/ha per day in $GS_3$) | 118.7 | 58.6 - 273.4 |
| Seeds per head (no) | 1287 | 469 - 2161 |
| Seeds/head per day in $GS_2$ (no) | 30.4 | 10.0 - 61.7 |
| Seed weight (mg) | 36.6 | 24.0 - 54.6 |
| Grain-filling rate (g/1000 per day) | 0.986 | 0.438 - 2.293 |
| Nodes/head (no) | 10.6 | 5.3 - 13.5 |
| Branches/head | 54.6 | 29.8 - 92.0 |
| Branches/node (no) | 5.2 | 3.6 - 8.0 |
| Seeds/branch (no) | 24.7 | 8.8 - 62.6 |
| Seeds/node (no) | 322.4 | 51.3 - 232.4 |
| Total dry weight (kg/ha) | 14750 | 7260 - 32000 |
| Seasonal growth rate (kg/ha per day) | 119 | 61 - 248 |
| Harvest index (%) | 41.5 | 16.4 - 55.7 |

grain at harvest consists largely of nitrogen transferred from vegetative parts. The ratio of grain nitrogen to total nitrogen expressed as percent can therefore be used to evaluate the NTE (nitrogen transfer efficiency) at different total uptakes.

The total nitrogen uptake per plant varied from 0.22 to 1.14 g, averaging 0.63 g. The NTE varied from 57.8 to 86.6 percent, and this difference was significant at the P = 0.05 level. The mean NTE for all genotypes was 77.0 $\pm$0.29 percent. However, at a given total uptake there were genotypes with NTE of more than 77.0 percent. For example, at total nitrogen uptake of 0.8 g/plant, NTE varied between 67.9 and 86.6 percent, suggesting a large scope for developing plant types with above-average NTE. If the amount of plant nitrogen transferred to the grain varied only slightly, the grain yield would show a strong negative correlation with nitrogen and protein percentage of the grain. In the present study the proportion of plant nitrogen transferred to the grain at harvest varied significantly (P = 0.05). It is thus expected that the grain yield would show a weak negative correlation with grain-nitrogen concentration, as was the case in this study (r=0.36*).

An increase in grain-nitrogen content is expected to be reflected in the decrease of nitrogen in leaves and stem. This was reflected in the negative associations between NTE and the nitrogen content of stover (r = 0.54***), stem (r = 0.46**), and leaves (r = 0.55***). The grain-nitrogen yield was positively related to the amount of nitrogen taken up (r = 0.95***), and to the nitrogen content of stover (r = 0.45**), stem (r = 0.36*), and leaves (r = 0.31*). An increase in grain nitrogen can therefore occur by an increase in the plant nitrogen. Grain nitrogen was strongly correlated (r = 0.77***) with the total biomass. Therefore, the variation in plant size is likely to be associated with the variation in grain-nitrogen content. Differences in grain-nitrogen percentage of various genotypes were non-significant, but differences among genotypes in grain-nitrogen content (grain N% x grain yield) were statistically significant (P = 0.05).

NTE and Harvest Index were strongly positively correlated (r = 0.83***) indicating that the achievement of a high harvest index requires a high NTE. The grain yield was positively correlated with the total plant nitrogen (r = 0.51***), grain-nitrogen content (r = 0.58***), and NTE (r = 0.33*). The negative significant correlation (r = 0.36*) between grain yield and grain-nitrogen percentage was small enough to suggest that high-yielding genotypes with a high grain-nitrogen concentration could be obtained, provided genotypes were developed which had an above-average nitrogen uptake, and which at a given yield could transfer the maximum portion of the nitrogen to the grain.

**Drought Resistance**

Seventy-four genotypes were evaluated in the field for drought-resistance response to a stress period of 30 days beginning at the panicle-initiation stage. The material tested included 40 adapted genotypes and germplasm lines and 30 fertiles from the drought-resistant population NP9BR. We found a wide range in the whole-plant response to water stress, and developed an evaluation procedure based on the effect of stress on the length of the growth cycle, absolute yield under stress, and decrease in yield under stress relative to the yield under no stress. With this procedure, genotypes can be classified as resistant or susceptible; resistant genotypes can be grouped into two major response classes—*avoidant* and *tolerant*. For a genotype to be accepted as drought resistant, it should be capable of producing a yield under experimental stress conditions of 2000 kg/ha and/or have a relative yield reduction of no more than 30 percent when compared to its yield under no stress. Resistant genotypes with *avoidant* response are those whose growth cycle is either telescoped or not affected or extended by less than 7 days. The genotypes are able to grow during drought and complete their reproductive phase. Some of these genotypes have an ability to produce a "second" yield from newly formed tillers during the post-stress period. Resistant genotypes with *tolerant* response are those whose growth cycle is extended by more than 7 days up to 30 days or more. These genotypes make some or no growth during the stress period, and depend greatly or completely on post-stress recovery for producing a yield. We feel that the evaluation system must take into account the effect of stress on the length of the growth cycle. This will enable the development of avoidant genotypes required in areas where rainfall is low and duration of the growing season limited with little or no opportunity for post-stress recovery, and tolerant genotypes for areas where (due to longer growing season) time is available for post-stress recovery after a mid-season drought.

**Seedling, Root, and Panicle Development**

Seventy-eight genotypes were studied in petri dish, pot, and field. The initial dry weight of seeds was positively correlated with the dry weight (of seed) lost during the first 5 days in the petri dish and at emergence (r = 0.90**), dry weight of new growth (radicle and plumule) at the end of the fifth day in petri dish (0.55*), and at emergence in the field (r = 0.88**). Initial dry weight of seeds [and dry weight (of seeds) lost at emergence] was positively correlated with the dry weight of plumule (r = 0.52**), dry weight of radicle (0 85**), and the ratio of radicle dry weight to plumule dry weight (r = 0.76**). Dry weight of seed lost during the first 5 days in the petri dish and in the pot and field at emergence was positively correlated with the dry weight of new growth (r = 0.89**). Dry weight of new growth at emergence was positively correlated with the dry weight of seedlings at 15 days in the field and at 30 days in the pot (r = 0.48**). Therefore the absolute weight of seed reserves mobilized for new growth during germination and seedling size at 5, 15, and 30 days increases with increase in seed size. However, the association between seed size and seedling size at 15 and 30 days after emergence, although significant, is not strong. It indicates that big seedlings at 15 and 30 days are produced from big seeds, but not all big seeds produce big seedlings. This is because the photosynthetic area and efficiency also influence the rate of growth of seedlings after emergence. The evaluation procedure now being used to identify seedling vigor is therefore based on the growth performance of genotypes during the 15-day period after emergence in the field compared to a check.

A brick-chamber method was tested for its usefulness in studies of root development by growing CSH 1 and 22E in three chambers which were then dismantled at 45, 60, and 75 days. The method is capable of showing differences in root development, and will permit the evaluation of more genotypes. For example, the average dry weight of roots per plant at all stages was greater in 22E than in CSH 1 (32 and 25 g respectively at 75 days); the average length of each main root at all stages was greater in 22E than in CSH 1 (35 and 27 cm respectively at 75 days); and root/shoot ratio at all stages was greater in 22E than in CSH 1 (0.48 and 0.35 respectively at 75 days).

A field study on panicle development in CSH 1, 22E, and their parents was made during $GS_2$ and $GS_3$. Results have not been fully analyzed, but it appears that CSH 1 does not deviate appreciably from its parents in its developmental timetable and panicle characteristics, whereas 22E deviates greatly from its parents.

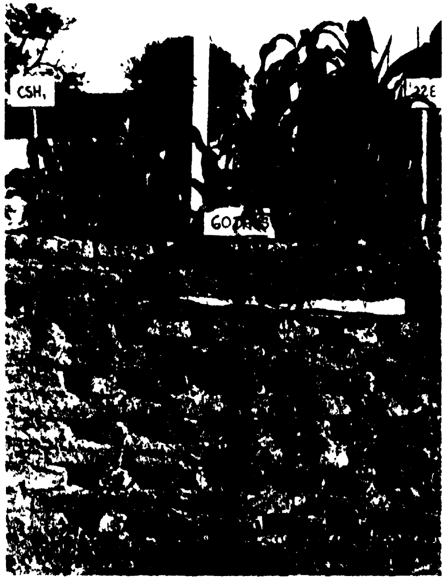
#### Physiological Source Material

Source material for various physiological attributes were identified for use in the breeding program. These include 25 genotypes with seedling vigor, 8 genotypes with above-average nitrogen uptake and transfer efficiency to the grain, 20 genotypes with carbohydrate source and/or sink attributes, and drought-resistance genotypes.

#### Looking Ahead in Sorghum Physiology

A major effort in sorghum physiology in 1976-1977 will include developing the physiology breeding population, incorporating sources of plant characteristics related to yield into a working population which will provide the basis for improving yield potential.

Efforts to screen for drought resistance will continue; experiments are planned to provide data which will verify findings of the year just past, and to investigate further the effects of stress on crop growth and yield.




*Seedling development in cereals was studied by planting sorghum and pearl millet in brick chambers, then dismantling the chambers at specific stages of growth. The dismantled chamber provided easy access to the roots.*

Developmental physiology work will include completion of the studies on panicle growth and development, continued studies on seedling vigor and root growth and development, and preliminary investigations of the nature of mechanical resistance to *Striga* infection.

## Entomology

#### Shoot-fly Biology

Work over several seasons has confirmed that *A. soccata* is dominant at ICRISAT Center;

more than 95 percent of the flies bred from sorghum were of this species. *A. eriochloae* was recovered from ratooning sorghum tillers for a limited period in December 1975 (Table 11). *A. soccata* was also recorded from maize, pearl millet, *Echinochloa colonum*, *Eriochloa procera*, *Cymbopogon* sp., and *Paspalum scrobiculatum*. A wide range of other *Atherigona* species was reared from various cereals and grasses during the year (Table 12). *A. falcata* was dominant in grasses. *A. approximata* was common, but not damaging in *Pennisetum americanum* (L).

Good progress was made on development of an attractant for sampling shoot-fly populations. The ability of fish meal to attract shoot fly was enhanced by the addition of ammonium sulphide and Brewer's yeast (Table 13). Catches with unsupplemented fish meal were greatest 3 to 4 days from admixture of the attractant and water (Table 14). During a 2-week period of preliminary trials, catches per day from the better treatments averaged 120 per trap. Identification of species trapped in sorghum fields indicated a preponderance of *A. soccata* (in excess of 90%). *A. orientalis* and *A. falcata* were also common. The reasons why catch is maximized at 3 to 4 days, as well as the action of the chemical constituents involved in attractivity, are being studied. Skatole has been shown to be somewhat attractive, but addition of fertilizers or ammonia was detrimental to the effectiveness of fishmeal/ammonium-sulphide/Brewer's-yeast mixtures. A mixture of sorghum dead hearts and water attracted significant catches of shoot fly.

**Table 11. Species of *Atherigona* and *Acritochaeta* bred from seedlings of a range of sorghum cultivars, 5 Sep to 7 Dec 1975.**

| | (no) |
|---|---|
| Total | 1 585 |
| males | 562 |
| females | 1 023 |
| *Atherigona* males | |
| *A. soccata* | 548 |
| *A. approximata* | 1 |
| *A. eriochloae* | 7 |
| *Acritochaeta* males | |
| *A. orientalis* | 2 |
| Others | 4 |

Oviposition/behavioral studies were begun. Preliminary results were in line with Soto's unpublished data indicating that fecundity of females was considerably increased by feeding on Brewer's yeast. Studies on oviposition at differing plant spacings showed that the maximum numbers of eggs were laid at close spacings but the maximum percentage of plants attacked was obtained at spacings between 10 and 20 cm (Table 15). Thus screening should be carried out at 20-cm interplant for maximum efficiency, while interlards should be sown at around 1 cm to maximize shoot-fly build up. Attempts to obtain aestivating pupae of *A. soccata* were unsuccessful.

### Screening for Shoot-fly Resistance

Many sorghum germplasm lines were screened over the three seasons covered by this report. These included lines reported as resistant from AICSIP or from West Africa, and previously unscreened lines from the world collection. New accessions from farmers' fields were tested. Much of the material in the breeders' populations was rated for susceptibility. In all instances Starks' interlard/fish meal technique was used and satisfactory levels of oviposition achieved.

Lines selected as showing marked oviposition non-preference to shoot fly included IS 4664, 2138, 4506, 2201, 2122, 2269, 2312, 2146, 5656, 5383, and 1082. Several of the West African/Indian crosses–IS 5604 × 23/2, IS 5694× 453, and IS 5383 × 453–showed marked non-preference. Some antibiosis was possibly present in some other lines in which IS material was crossed to WABC. Some 10 hectares of sorghum, representing more than 1 500 lines, were screened.

**Table 12. Host plants and *Atherigona* sp. and *Acritochaeta* sp. records from ICRISAT Center.**

| | Total | Male | Species of *Atherigona* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *soc-cata* | *approxi-mata* | *fal-cata* | *oryzae* | *orien-talis* | *pulla* | *erioch-loae* | *mili-aceae* | *laeta* | *punc-tata* | spp |
| | (no) | (no) | (no) | (no) | (no) | (no) | (no) | (no) | (no) | (no) | (no) | (no) | (no) |
| *Zea mays* Linn | 5 | 5 | 2 | | 1 | | 1 | | | | | 1 | |
| *Pennisetum typhoides* Stapf and Hubb | 90 | 28 | 7 | 21 | | | | | | | | | |
| *Eleusine coracana* Gaertn. | 1 | 1 | | | | | | | | 1 | | | |
| *Panicum miliaceum* Linn. | 3 | 1 | | | | | | 1 | | | | | |
| *Panicum psilopodium* Trin | 168 | 67 | | | 1 | | | 66 | | | | | |
| *Cynodon dactylon* Pers. | 8 | 3 | | | | | | | | | 1 | | 2[a] |
| *Dactyloctenium aegyptium* P. Beauv | 6 | 2 | | | | | | | | | | | 2[b] |
| *Digitaria adscendens* (HBK) *var criniformis* Henr. | 189 | 81 | | | 1 | 80 | | | | | | | |
| *Echinochloa colonum* Link | 223 | 90 | 3 | | 82 | 3 | | 2 | | | | | |
| *Echinochloa crusgalli* P.Beauv | 47 | 22 | | | 19 | | | 3 | | | | | |
| *Tschaemum pilosum* Wight | 1 | 1 | | | 1 | | | | | | | | |
| *Chloris barbata* Sw. | 4 | 1 | | | 1 | | | | | | | | |
| *Eragrostis cilianensis* Vignolo-Lutati | 1 | 1 | | | | | | | | | | 1 | |
| *Eriochloa procera* C.E. Hubb | 58 | 17 | 2 | | 2 | | | 1 | 3 | | | 9 | |
| *Cymbopogan* sp. | 1 | 1 | 1 | | | | | | | | | | |
| *Setaria italica* P. Beauv | 1 | 1 | | 1 | | | | | | | | | |
| *Paspalum scrobiculatum* Linn. | 2 | 2 | 2 | | | | | | | | | | |
| Unidentified grass | 78 | 26 | | | 24 | 2 | | | | | | | |
| Unidentified grass | 20 | 8 | | | 8 | | | | | | | | |

[a] *A. reversura* ssp. nov. and *A.* sp. nov.

[b] *A. atripalpis*

Table 13. Catches of *Atherigona* sp. (mainly *A. soccata*) with different attractant treatments.

| Treatment | Mean number of flies caught | |
|---|---|---|
| | Experiment 1 | Experiment 2 |
| | (no) | (no) |
| Water control | 4.0 | 2.4 |
| Fish meal | 113.3 | 96.8 |
| Brewer's yeast | — | 4.0 |
| Ammonium sulphide | — | 4.0 |
| A. sulphide + fish meal | — | 43.5 |
| Brewer's yeast + fish meal | — | 97.4 |
| A. sulphide + brewer's yeast | — | 178.1 |
| A. sulphide + brewer's yeast + fish meal | — | 241.8 |
| L.S.D | 58.08 (504) | 184.21 (1404) |

Several lines showing nonpreference have been studied in detail in collaboration with the Cereal Physiology unit and COPR (Center for Overseas Pest Research) to attempt to elucidate the reasons for the reduction in egg numbers.

Preliminary information suggests some relaonship between trichome number on the nderleaf surface and egg number. Behavioral tudies also indicate that chemoreception may e involved in selection of oviposition site.

### tem-borer Biology

evelopment of a suitable medium for rearing *hilo partellus* in large numbers for screening ork progressed. Counts of damage under atural *Chilo* attack were taken on lines during reening for shoot fly.

Detailed studies of *Chilo* carry-over in stalks of various cultivars were continued. Of the larvae collected in December 1974, 11 percent did not pupate until late June 1975. Parasitism rates were high. Identified parasites included *Sturmiopsis inferens* Tns., *Halidaya luteicornis* Walk., *Carcelia* sp., *Bracon chinencis* Szepl., and *Xanthopimpla stemmator* Thun.

Experiments on carry-over again indicate that a significant proportion of the stalks of all cultivars at ICRISAT Center carry *Chilo* at the start of the season. Regular sampling of stalks from farmers' fields from March through May 1976, however, failed to locate the insect (Table 16).

Testing of the synthetic pheromones of *Chilo* recently synthesized at the Tropical Products Institute of London was successful. Various trap designs were tested and a square pan trap with a lid adopted. In initial trials, the high-titer vials (cp 75/20) caught more moths than the

**Table 14. Catches of *Atherigona* sp., (mainly *A. soccata*) from initial mixing with water of fish meal attractant.**

| Time Units | Mean number of flies caught | |
|---|---|---|
| | Experiment 3[a] | Experiment 4[b] |
| | (no) | (no) |
| 1 | 29.0 | 45.5 |
| | 49.5 | 136.7 |
| | 57.9 | 99.9 |
| | 100.5 | 120.9 |
| | 43.8 | 72.9 |
| | 81.3 | 63.5 |
| 7 | 48.5 | 47.1 |
| L.S.D. | 56.2 (58df) | 64.36 (96df) |

[a] 1-day units [b] 2-day units

low-titer (cp 75/19) and there was a rapid drop off of efficiency after 4 days. There was a strong indication, subsequently repeated regularly, that catches were highest after rain. More moths were caught at crop height than on top of 2-m bunds or at ground level. Subsequent trials indicated that utilization of the pheromones in separate vials was more efficient than using high-titer vials or mixed major and minor components in natural proportions. Vials were not efficient after 16 days. Catches using virgin female *Chilo* were disappointingly low, and the minor component used alone caught no moths.

Light-trap records of *Chilo* are being maintained and will be compared with data obtained from pheromone traps. Indications are that a constant low level of moth activity occurs throughout the year; peaks of activity occurred in August and September and this year, possibly owing to unseasonal showers, in April and May. Population levels are relatively low in December, January, and February.

## Midge

Data on midge is preliminary. Several para-

**Table 15. Effect of interrow plant spacing on shoot-fly oviposition at ICRISAT Center, 1975.**

| Spacing | Mean number and percentage of plants with eggs | | | | | |
|---|---|---|---|---|---|---|
| | Site 1 | | Site 2 | | Site 3 | |
| (cm) | (no) | (%) | (no) | (%) | (no) | (%) |
| 1.0 | 217 | 60.7 | 247 | 48.1 | 234 | 35.3 |
| 2.5 | 159 | 67.7 | 202 | 67.6 | 148 | 54.9 |
| 5.0 | 113 | 74.7 | 114 | 78.9 | 100 | 76.8 |
| 10.0 | 59 | 78.2 | 45 | 79.4 | 45 | 76.4 |
| 20.0 | 39 | 79.4 | 32 | 85.4 | 32 | 88.0 |
| S.E. ± | 10.1 | 3.90 | 10.9 | 4.02 | 9.3 | 2.91 |
| P | 0.001 | 0.05 | 0.001 | 0.001 | 0.001 | 0.001 |

Table 16. Summaries of observations of *Chilo partellus* on stooked sorghum[a] material, 1975-1976.

| Cultivar | Date of observation | Stalks sampled | Larvae | Pupae normal alive | Pupae normal cases | Pupae parasitized alive | Pupae parasitized cases |
|---|---|---|---|---|---|---|---|
| | | (no) | (no) | (no) | (no) | (no) | (no) |
| CSH-1 | 5 Dec 75 | 200 | 35 | — | 7 | — | 8 |
| Swarna | 5 Dec 75 | 200 | 29 | — | 4 | — | 6 |
| Local | 5 Dec 75 | 100 | 15 | — | 5 | — | 1 |
| CSH-1 | 5 Jan 76 | 200 | 20 | 1 | 12 | — | 13 |
| Swarna | 5 Jan 76 | 201 | 15 | — | 4 | 2 | 10 |
| Local | 4 Jan 76 | 101 | 21 | — | 2 | — | 3 |
| Farmers' field | 4 Jan 76 | 100 | 14 | — | 1 | — | 1 |
| CSH-1 | 6 Feb 76 | 125 | 20 | 3 | 7 | 3 | 5 |
| Swarna | 6 Feb 76 | 200 | 20 | 5 | 21 | — | 6 |
| Local | 6 Feb 76 | 104 | 16 | 1 | 7 | — | 3 |
| Farmers' field | 6 Feb 76 | 100 | 6 | 1 | 3 | — | 4 |
| CSH-1 | 5 Mar 76 | 200 | 10 | 4 | 10 | 4 | 12 |
| Swarna | 5 Mar 76 | 200 | 3 | 3 | 15 | 2 | 3 |
| Local | 5 Mar 76 | 100 | 2 | 1 | 5 | 1 | 2 |
| Farmers' field | 5 Mar 76 | 100 | Nil | 1 | 2 | — | 1 |
| CSH-1 | 5 Apr 76 | 200 | 8 | — | 21 | 1 | 8 |
| Swarna | 5 Apr 76 | 200 | 2 | 3 | 4 | 1 | 13 |
| Local | 5 Apr 76 | 100 | 2 | — | 7 | — | 3 |
| Farmers' field | 5 Apr 76 | 100 | Nil | — | — | — | 1 |

[a] Stooked sorghum is sorghum stored in shocks.

sites, including *Eupelmus popa* Gir., *Apanteles* sp., and *Tetrastichus* sp., have been identified. Midge attack at ICRISAT Center is generally low; screening for midge resistance will have to be carried out elsewhere. Midge emergence was found to occur just before daybreak in the April-May period; peak emergence was recorded between 0300 and 0500 hours.

**Looking Ahead in Sorghum Entomology**

The prime task of the Entomology group will continue to be location of germplasm lines with superior pest-resistance qualities. Progressively the work will move towards testing of material coming forward from breeders and helping to build up levels of resistance in those lines which have superior agronomic and quality traits. With the establishment of the cooperative programs overseas, comparisons of the pest spectrum in different countries, together with their predators and parasites, will be made. There will be a considerable exchange of seed material between core and cooperative programs.

Work on the biology of the main pest species and their seasonal distribution and carry-over in unfavorable climatic situations will continue. Surveys on the viruses of lepidopterous pests will be made, and the work on pheromones of *Chilo partellus* will be expanded, as will the work on midge biology and the problem of midge screening.

## Pathology

### Identification of Resistance to Grain Molds

A total of 4 036 germplasm and breeding lines were screened for resistance to grain molds in the field during rainy season 1975. The entries were confined to those with white, yellow, dull-yellow, or light-red grains. Five heads from each line were inoculated with *Fusarium* or *Curvularia*, or a mixture of both. Inoculum was prepared by growing isolates of these fungi on autoclaved sorghum grain. The extended rains provided an excellent environment for this test and considerable natural mold developed in uninoculated heads of highly susceptible lines. Thus the lines received a severe test for grain-mold reactions. The lines were scored on a scale of 1 to 9 (1, no mold; 9, completely molded). Only three lines (IS 9327, IS 9333, IS 9530) showed a "1" reaction, 90 lines were in reaction category "3" (Table 17). The proportion of lines in categories "7" and "9" are greater in the inoculated heads, indicating the usefulness of the inoculations even under conditions suitable for natural mold development.

During post-rainy season 1975, five head-rows of the 93 lines in reaction categories "1" and "3" from the rainy-season trial were planted, in an attempt to retest their mold reactions and to multiply seed. Heads were again inoculated with fungal isolates used in the rainy-season trial and covered immediately with white paper bags over polyethylene bags to maintain humidity around the developing grains. There was poor seed set on bagged

**Table 17. Numbers of lines showing various grain-mold reaction categories in germplasm screening, rainy season 1975.**

| Inoculum | Disease reaction category[a] | | | | |
|---|---|---|---|---|---|
| | 1 | 3[b] | 5 | 7 | 9 |
| | (no) | (no) | (no) | (no) | (no) |
| *Fusarium* | 3 | 178 | 1 598 | 2 039 | 218 |
| *Curvularia* | 3 | 254 | 1 924 | 1 795 | 60 |
| Bagged-non-inoculated | 3 | 319 | 2 326 | 1 397 | 11 |
| Non-treated | 3 | 357 | 2 345 | 1 324 | 7 |

[a] 1 = no mold, 9 = severe mold over entire head

[b] 90 lines were common to all treatments

heads in this trial, probably related to high temperatures developing within the bags. Despite the poor seed set, it was possible to observe differences between the inoculated heads of the known high-susceptible checks and the test lines, which again appeared less susceptible. Noninoculated heads of all lines were entirely free from molds.

### Microfloral and Seed-treatment Studies on Grain Harvested in the Rainy Season

Seed of cv CS-3541 harvested from the rainy season 1975 crop was examined and sorted into visually clean or molded samples. Viability, microfloral infection, and the effects of treating with four fungicides at three concentrations (0.2, 0.5, and 1%) were then tested. Results are summarized in Table IV.

At the 0.2- or 0.5-percent concentrations, not one of the fungicides improved germination over that of the control although benomyl reduced fungal infection substantially at all levels. Fungi predominating on the "clean" grain were *Fusarium*, *Olpitrichum*, and *Tricothecium*, and on the moldy grain *Fusarium*, *Curvularia*, and *Olpitrichum*. The degree of infection of the clean grain is surprising and needs further analysis, particularly as some *Fusarium* species produce powerful mammaliotoxic mycotoxins.

### Leaf Disease and Downy Mildew Screening

During rainy season 1975, various lines developed a high incidence of grey leaf spot, zonate leaf spot, and sooty stripe, and 100-percent SDM (sorghum downy mildew) infection was achieved on two susceptible varieties in garden plots. It therefore seems possible that screening for resistance to SDM and some leaf diseases, using infector lines (spreader rows), may be practicable during the rainy season. Results of similar attempts in the post-rainy and the hot dry seasons were discouraging.

### International Sorghum Disease-resistance Testing Program

This program has been developed in consultation with AICSIP, Texas A and M University, and the West Africa OAU/STRC JP 26 project. Three nurseries have been distributed to locations in the SAT for planting during rainy season 1976 (Table V).

### Looking Ahead in Sorghum Pathology

New germplasm will be screened for resistance to grain mold. The lines selected in 1975 will be tested in the International Sorghum Grain Mold Nursery at several Indian and African locations in 1976.

**Table IV**

| | Grain | | | |
|---|---|---|---|---|
| | Apparently clean | | Moldy | |
| Treatment | Germination | fungal infection | Germination | Fungal infection |
| | (%) | (%) | (%) | (%) |
| None | 20 | 98 | 4 | 98 |
| Agrosan 1% | 30 | 56 | 4 | 59 |
| Demosan 1% | 28 | 84 | 1 | 99 |
| Thiran 1% | 33 | 40 | 8 | 57 |
| Benomyl 1% | 29 | 15 | 2 | 18 |

**Table V**

| Trial | Locations (no) | Entries (no) |
|---|---|---|
| 1. Grain-mold Nursery (IS GMN) | 12 | 55 |
| 2. Leaf-disease Nursery (IS LDN) | 9 | 60 |
| 3. SDM Nursery (IS DMN) | 7 | 35 |

The International Sorghum Downy Mildew Nursery and the International Sorghum Leaf Disease Nursery will be operating in several Indian and African locations. These trials will be visited by ICRISAT pathologists, who will provide assistance in data recording.

During post-rainy season 1976, various inoculation methods for promoting charcoal rot will be evaluated.

## Nutritional Quality

Routine screening was carried out on about 7000 sorghum samples for protein and lysine

*A major objective of the microbiology program is to evaluate nitrogen-fixing ability of micro-organisms living on the roots of cereals.*

(basic amino acids) during 1975-1976. The mean value was 10.5, the mode was 11, and the range was 6.0 to 16.0 percent.

The DBC value (dye-binding capacity, the UDY-instrument reading representing percent transmission) was taken for a constant protein level of 800 mg for all samples, giving an estimate of total basic amino-acids. For the 7 171 samples analyzed, the mean DBC value was 24.0, the modal value was 21.0, and the range was 15.0 to 51.0.

The source and description of samples analyzed during 1975-1976 are presented in Table 18.

Initially, protein was estimated by the biuret method, but it was noted that this method was underestimating, especially at low protein percentages. Therefore, samples which showed high DBC were analyzed for their protein content by the micro-Kjeldahl method, then a fresh DBC determination was made. Later, analyses for protein were carried out either by the micro-Kjeldahl method or by the Technicon auto-analyzer method.

# Microbiology

A total of 115 sorghum lines, hybrids, and related species which performed well under both low- and high-fertility conditions were grown under low-fertility conditions (20 kg N, 9 kg P/ha applied) during post-rainy season 1975 and evaluated for their ability to stimulate the nitrogenase activity of rhizosphere bacteria. Washed-root systems were assayed by acetylene reduction in 320-ml bottles after an overnight preincubation under circa 1% $O_2$ in argon or nitrogen. Nitrogenase activity varied between lines up to forty fold, with a maximum activity of 4.3 µmol/plant per hour or 1.2 µmol-g dry weight of root per hour. In lines

**Table 18. Protein-content and DBC ranges of sorghum, 1975-1976.**

| Date received | Samples | Source and Description | Protein range | DBC range |
|---|---|---|---|---|
| | (no) | | (%) | |
| Mar 75 | 38 | P721 Mutant and Degan Village Bulk | 9.2 - 16.9 | 20.5 - 30.0 |
| Apr 75 | 100 | World collection (without sub-coat) - KEPR | 8.0 - 15.9 | 19.0 - 30.0 |
| May 75 | 1 911 | Purdue University-single and three-way crosses | 6.0 - 16.0 | 17.5 - 44.5 |
| May 75 | 2 231 | Purdue University-single and three-way crosses | 6.0 - 16.0 | 15.5 - 51.0 |
| Nov 75 | 2 552 | Material harvested from post-rainy season 1976 | 5.6 - 17.9 | 15.0 - 45.0 |
| Dec 75 | 16 | Rainy season, black soil, four levels of N fertilizer | 5.0 - 9.8 | 25.5 - 44.0 |
| Dec 75 | 231 | Group I - High DBC-value, Group II and III | 6.4 - 17.4 | 17.5 - 30.0 |
| Jan 76 | 92 | Farmers' samples, Khammam District, post-rainy season 1975 | 5.4 - 12.8 | 19.0 - 34.0 |

stimulating much activity some plants had little activity so that differences between replicate plants could be as much as eighteen fold. Variability in plant growth induced by shoot-fly attack, as well as differences in oxygen tension around the roots during the assay, may be partly responsible. Much nitrogenase activity was associated with 10 entries which included the hybrids CSH-1 and CSH-5, and *Sorghum halepense*. Activity was greater after flowering than before, and continued well into the grain-filling stage for these irrigated plants. Most plants did not appear to be nitrogen deficient. Our work will concentrate first on developing a suitable acetylene reduction assay system so that we can reliably identify lines which stimulate much nitrogen fixation.

## Looking Ahead in Sorghum Microbiology

ICRISAT microbiologists plan to measure the amounts of nitrogen fixed by root-associated bacteria, and determine the contribution of this nitrogen fixation to nitrogen uptake by the plant. The technique of using $^{15}N$-labeled $NO_3$ and $N_2$ will be employed. Relationships between the reduction of acetylene and the reduction of nitrogen by root associations will also be studied, as well as the influence of fertilizer on nitrogen fixation.

# PEARL MILLET

# Pearl Millet

During the year of this report, three breeding crops were harvested—that of rainy season 1975 (the normal crop), that of the post-rainy season (planted in October 1975 and harvested in January during the cool part of the dry season), and that of the hot dry season (harvested in May 1976).

Crop improvement work on millet consists of the integration of breeding, germplasm, pathology, entomology, physiology, biochemistry (grain), rotation and intercropping agronomy, and microbiology. These activities are covered in the following pages.

## Germplasm

At present, ICRISAT maintains 4697 pearl millet accessions. These include exotic collections from West and East Africa, the IP (Indian *Pennisetum*) collection, inbred lines, disease-resistance lines from various sources, and wild pecies of *Pennisetum* (Table 19). During the 'ear, 167 IP accessions were received through he courtesy of ALAD in Lebanon. These vere grown in post-rainy season 1975 and sev-ral interesting grain types were identified, ncluding one with yellow pericarp. A planting f 110 local cultivars of Uttar Pradesh, ceived from G.B. Pant University of griculture and Technology at Pantnagar, was own in rainy season 1975; all were observed be late, very tall with thin stems and small ads, and all susceptible to downy mildew.

The manner in which the germplasm is being ed to generate source material for breeding is picted in Figure 10. In this regard, our first ur base composites constituted at RISAT—which have now completed one cle of recombination and selection—utilized 0 lines chosen from the germplasm collection ee Breeding project 1). A working collection the objective of developing and classifying ollection of lines with agronomic interest built by the breeding group from the germ-m collection.

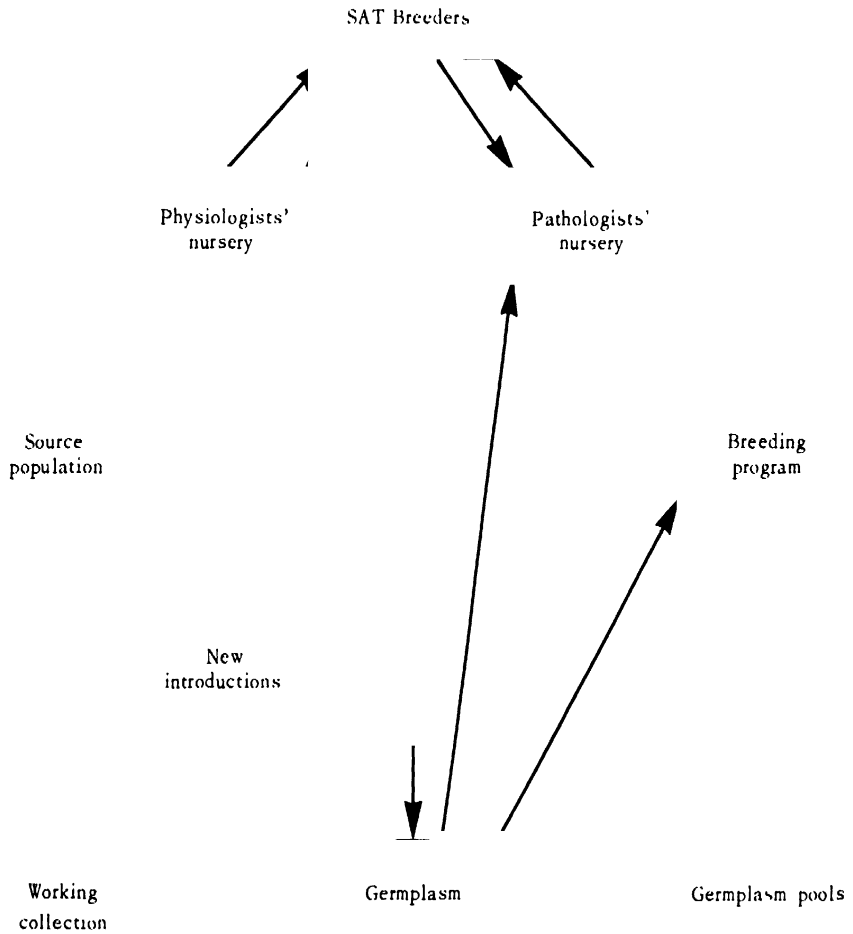
In view of the need to conserve genetic resources threatened by natural disasters, as well as by human activity, a millet-collection expedition into the Sahel region of Africa was organized, with support of FAO and UNEP, in late 1975 by ORSTOM (France's Organisation des Recherches Scientifiques et Techniques d'Outre-Mer). The objective of the expedition, in which ICRISAT participated, was to collect as much as possible of the remaining native cultivars of millet, as well as intermediate forms and wild species of *Pennisetum* capable of hybridizing with pearl millet. Some of these wild species introgress with the cultivated types to give rise to "intermediate forms;" these forms are a valuable constituent of the "genetic reservoir" of pearl millet. Through its participation in the Sahel expedition, ICRISAT was able to add 255 cultivated types and 195 intermediate forms from Upper Volta and Niger to its pearl millet germplasm collection.

#### Looking Ahead in Millet Germplasm

Several long-term trials will be initiated to determine the best way to preserve variability in gene pools and separate accessions; this will be in preference to conservation as inbred lines. ICRISAT's germplasm efforts will follow, as nearly as possible, the proposals of the Working Committee on Sorghum and Millets of IBPGR (International Board for Plant Germplasm Resources). Efforts will be made to obtain pearl millet accessions from Cameroon, Central African Republic, Mali, Niger, Upper Volta, Togo, Senegal, Mauritania, and the Sahara oases, as there are gaps in these holdings at ICRISAT Center. The Center's collection contains very few entries from Asian countries, especially China. In India, some recollecting is needed in order to reconstitute the germplasm in a more unaffected way. The first large-scale effort will be in Rajasthan, from which we now have only a few accessions.

**Table 19. Pearl millet accessions at ICRISAT (March 1976).**

| Description | | Number of entries |
|---|---|---|
| Exotic Collections (West and East Africa - includes lines, varieties, and composite populations) | | 367 |
| Indian Pennisetum (I.P) collection (IP 1 to IP 3018. Collections obtained from Lebanon, Bangkok, Rajendranagar, Jamnagar, and Ludhiana; duplicate entries ignored for totalling) | | 1 875 |
| Jamnagar (Gujarat, India) (inbred lines and selections among them) | | 1 873 |
| Downy mildew-resistant material (Source: Dr. Safeeulla, Univ. of Mysore, India) | | 119 |
| Promising lines from Maharashtra (including local collections) | | 108 |
| Local cultivars from Uttar Pradesh, India | | 110 |
| Miscellaneous (inbred lines) | | 33 |
| Disease-resistance inbreds (Dr. N.V. Sundaram, IARI, New Delhi) | | 170 |
| Disease-resistance lines (downy mildew, ergot, smut. From CNRA, Senegal) | | 9 |
| Male-sterile lines | | |
| (i) $A_1$, $A_2$, and $A_3$ sources | | 13 |
| (ii) Downy mildew "resistant" B lines (Dr. G.W. Burton, Research Geneticist, ARS (USDA), and University of Georgia Agricultural Experiment Station, USA) | | 4 |
| Wild species of *Pennisetum* | | 11 |
| Interspecific crosses | | 5 |
| | Total | 4 697 |




ines with desirable
gronomic characteristics:
uration, Disease
esistance, Drought tolerance,
warfing, Tillering, Protein
ontent, Grain weight,
ew restorers, etc.

Assembly of:
a. Cultivated forms (primitive and landraces)
b. Intermediate forms (Shibras)
c. Wild species
d. Advanced breeding lines
e. Lines of special interest (Apomicts, spontaneous/induced mutations)
f. Male-sterile lines and maintainers

Pooling based on morphological similarities for maintenance

**10. Utilization of pearl millet germplasm in breeding programs.**

Germplasm in hand will be compared with the existing catalog of IP numbers received from various sources; hopefully this will bring the material back to a more original constellation.

## Breeding

The ICRISAT pearl millet breeding program aims to develop sources of high-yield potential with good grain quality and broad adaptability, and to cooperate with and supply to national breeding and agronomy programs such genetic material and information whereby they can improve and stabilize farmers' yields. Major efforts are directed towards breeding for broad adaptability, for which a prime requisite is disease resistance.

The identification of broadly adapted types requires multilocational selection and testing, conducted on a global scale with the cooperation of breeders in national programs. To improve material so that it becomes attractive to cooperators, initial screening for adaptability and disease resistance must be done. To accomplish this, ICRISAT entered into agreements with the Haryana Agricultural University at Hissar (lat 29°N) and the Tamil Nadu Agricultural University at Coimbatore and nearby Bhavanisagar (lat 11°N) to conduct extensive breeding nurseries at two locations (6 and 5 ha, respectively), beginning in rainy season 1975, besides growing all material at ICRISAT Center (Patancheru, Hyderabad, lat 17°N). The ICRISAT breeder at Saria (lat 12°N) in Upper Volta was able to grow 2 ha of breeding material supplied by ICRISAT Center. The rainy season and the hot dry season at ICRISAT Center provide contrasting environments for growing pearl millet; the latter is ideal for drought resistance evaluations on a field scale.

By means of the nurseries at Hissar, Coimbatore, and Bhavanisagar, it was possible for ICRISAT scientists to select effectively for both location-specific and across-location performance, and for field resistance to downy mildew, grain smut, and rust (normally, these diseases are at low level at ICRISAT Center; see pearl millet Pathology). This has enabled us to select for wider adaptation and more confidently choose suitable breeding material for cooperators, and to generate new entries for the 1976 International Trials.

The breeding program contains projects with relatively advanced material as well as others with source or backup material, and also draws upon original variability found in the germplasm accessions. Two breeding approaches are being used. The first is that of population breeding (recurrent selection in constructed composites); the second is the more classical use of specific crosses between chosen varieties or lines followed by limited inbreeding. Both methods involve a range of contrasting genotypes representative of the different zones where millet is grown in the SAT, though in advanced material photoperiod sensitivity is reduced. From either of these approaches, varieties, synthetics, or hybrid parents are produced in addition to a range of lines and segregating progenies in a less-refined state suitable for breeders.

Disease resistance, drought resistance, yield and stability of yield, and grain quality (both visual and nutritional) are essential features of advanced material, but individually these are found separately or in lesser associations in germplasm. While it is necessary to continually select for these traits in advanced material, it is also necessary to identify better sources often found in the germplasm accessions and bring them into more advanced morphological backgrounds. It is in these areas that the pathologists, physiologists, microbiologists, and biochemists collaborate with breeders and germplasm scientists to identify source material and refine detection procedures. Pearl millet is a crossbreeding crop, thus source material may be kept as breeding pools undergoing mild selection with outstanding progenies being taken forward for inclusion in the advanced projects.

Good genotypes emerging from the program are first evaluated by ICRISAT scientists, and only then are they entered in national or International trials. In 1975 we started IPMAT-1 (the first International Pearl Millet Adaptation Trial) which contained 14 entries sent to 16 locations.

## Breeding Projects

Seven projects make up the pearl millet breeding program—

1) Advanced Composites I—Intrapopulation improvement:

    a. To improve the population performance *per se* of promising composites. Selection will be mainly for grain yield and quality, wide adaptation, stability of yield, and resistance to diseases and pests.

    b. To produce experimental varieties from elite groups of selected progenies.

    c. To draw improved partial inbred lines from each cycle of composite for use in the hybrid program.

These composites will be widely useful sources of germplasm for breeders in both the national and the regional breeding programs.

2) Advanced Composites II—Interpopulation improvement:

    a. To create complementary pairs of populations and select for increased heterosis between them for grain yield, disease resistance, and stability of yield, etc.

*Bagging operations in the crossing block of the breeding nursery.*

b. To identify hybrid combinations.

3) Source material (now includes project 6):

a. To develop and classify a collection of lines and populations with special characteristics of agronomic interest from the germplasm.

b. To maintain a collection of "intermediate forms" and wild *Pennisetum* species.

c. To form composites with sources possessing valuable characteristics which may not be in adapted backgrounds.

d. To maintain exotic populations.

4) Variety crosses and synthetics:

a. To create variability by crossing specific parents and to select progeny under several environments. Further intercrossing will be made between selections.

b. To identify suitable parents for creating synthetic populations.

c. To provide cooperators with elite segregating material.

5) Hybrids:

a. To generate and identify parental material to produce high-yielding, disease-resistant, stable hybrids developed either through the variety cross program or composite program, using the three cytogenetic systems of male sterility.

6) Working collections (now merged with project 3)

7) Yield testing:

a. To conduct trials on material (hybrids, synthetics, experimental varieties, inbreds, etc.) emerging from the breeding programs of ICRISAT Center and cooperating agencies to determine performance, stability, and adaptability.

8) International cooperation:

a. To channel seed and information in both directions between ICRISAT and other breeders of the SAT.

b. To conduct coordinated trials with entries from ICRISAT and from cooperating agencies.

In the Advanced Composites projects, the largest and most developed is that where populations are undergoing improvement (Project 1), since the formation of complementary pairs (Project 2) requires more time for initial evaluation of entries.

Eight composites were ready for testing as progenies in three to five environments during rainy season 1975 (Table 20). The Early, Dwarf, Medium, and Late composites and the Intervarietal Synthetic were made at ICRISAT Center, while the World Composite is from the breeding program in Nigeria, the Senegal Dwarf Synthetic from Senegal, and the Serere Composites are from Uganda. Seed limitations restricted the plantings to one replication per location in most locations, though two replications are desirable and will be used in the future.

One cycle of recurrent selection in the eight composites has been completed. Data were recorded on various characters such as head weight, days to 50 percent bloom, height, disease incidence, early vigor, and ear length. Plot size varied from 1.25 to 3.75 m², depending upon location and populations but for convenience in analysis all data were converted to a plot size of 3.75 m². Analysis of the first three characters, treating locations as replications, show that in all populations there are highly significant differences between progenies—indicating that adequate genetic vari-

**Table 20. Entries and replications of pearl millet populations at six locations in India, rainy season 1975.**

| Population and progeny type | Entries | ICRISAT Center (HF)[a] | ICRISAT Center (LF)[a] | Hissar | Coimbatore | Bhavanisagar | Saria, Upper Volta[b] |
|---|---|---|---|---|---|---|---|
| | (no) | (number of replications) | | | | | |
| Early Composite, $S_2$ | 638 | 1 | 1 | 2 | 1 | 1 | NT[c] |
| Dwarf Composite, $S_2$ | 532 | 1 | 1 | 2 | 1 | 1 | NT |
| Medium Composite, FS | 538 | 2 | 2 | 2 | 2 | NT | 1 |
| Late Composite, FS | 540 | 2 | 1 | NT | 1 | NT | 1 |
| World Composite, FS | 441 | 1 | NT | 1 | 1 | NT | NT |
| Senegal Dwarf Synthetic, $S_1$ | 281 | 1 | NT | 1 | 1 | NT | NT |
| Intervarietal Synthetic, $S_1$ | 496 | 1 | 1 | 2 | 1 | 1 | NT |
| Serere Composites, $S_1$ | 1325 | 1 | NT | 1 | NT | 1 | NT |

[a] HF = high fertility, 100 kg N, 20 kg P/ha, LF = low fertility, 20 kg N, 20 kg P/ha

[b] At Saria, many progeny failed because of being too early or susceptible to disease and yields were not recorded At this location, superior progeny were selected by eye at harvest

[c] NT = not tested at this location

bility exists and further selection will therefore be effective.

Several criteria in addition to yield, disease resistance, height, and bloom were used in selecting progenies. Those with undesirable characteristics such as lodging, incomplete head emergence, poor seed set, grain size, and grain color were rejected.

Progenies selected for recombination are a blend of those that have performed well at specific sites and those that have done well across all sites. A much more limited number of the same progeny are selected for producing experimental varieties. For a site where the population appears to be adapted and shows promise, an experimental variety is made by combining the top few progenies at that site. Similarly, an across-location experimental variety is composed of the few which have shown an evenly good performance over all sites. Such experimental varieties have several advantages over the larger group which is necessary to select for recombination, including a higher yield potential. Numbers of progenies selected from composites tested are shown in Table 21 and their relationships to total population performance plotted in Figures 11 and 12. The selection differential of the experimental varieties ranged from 28.9 to 73.1 percent (averaging 49%), which is almost 20 percent higher than the mean yield of those entries selected for recombination. The numbers and origins of experimental varieties produced from the 1975 intrapopulation improvement program are presented in Table 22.

Random mating was accomplished by controlled pollinations, using a balanced mixture of mass pollen collected from all but the entry to be pollinated. An equal amount of seed was then bulked for each entry. This method enforces a greater amount of random mating than does one generation of natural cross pollination.

Other composites, including additional dwarf ($D_2$) material from Senegal, will be ready for testing in 1976. We also expect to involve, for the first time, cooperators in the testing of composite progeny.

In Project 2, the third random mating was completed on the 1B and 1R population pair in late post-rainy season 1975. Four-hundred half sibs from each population were planted together late in the hot dry season of 1976 for the production of reciprocal full sibs. The parent plants are also being used to make labelled crosses on an A line to ensure selection of only good maintainers and restorers.

A total of 16 populations have been crossed in diallel. The "parents and $F_1$'s" will be tested in 1976 to determine the best complementary pairs.

Project 3 is composed of the Working Collection and the five Source Populations. ICRISAT will continue to collect millet germplasm from Africa and India and will continue in its role as a storehouse for the world's collection of pearl millet. At present, we are not equipped in either facilities or staff and therefore we have developed a Working Collection derived from our total collection to (i) develop and classify a collection of lines and populations with special characteristics or agronomic interest from the germplasm and (ii) to maintain a collection of intermediate forms and wild species. To begin with, about 340 lines were selected from the germplasm nursery planted during rainy season 1974. Of these, 65 were from Chad, 120 from India, 1 each from Mali and Mauritania, 34 from Niger, 43 from Nigeria, 11 from Senegal, 38 from Uganda, and 27 from Upper Volta. The selections were planted at ICRISAT Center in post-rainy season 1974 and at ICRISAT Center, Hissar, and Coimbatore during the rainy season of 1975. Exhaustive notes taken on each line included the following characteristics—

—days to 50 percent blooming

—plant height, head length, and plant girth (cm)

—tillering habit

—disease incidence (downy mildew, rust, smut, ergot)

—seed size (cm)

—protein content (%)

Table 21. Performance data of selected pearl millet population progenies in 1975.

| Population and Group | Entries | Mean Yields heads | Mean Yields grain[a] | Selection differential |
|---|---|---|---|---|
| | (no) | (kg/plot) | (kg/ha) | (%) |
| Early Composite | | | | |
| All progenies | 638 | 0.72 | 1 340 | — |
| Recombination | 37 | 0.94 | 1 750 | 30.6 |
| Across experimental varieties | 6 | 1.24 | 2 320 | 73.1 |
| Dwarf Composite | | | | |
| All progenies | 538 | 0.68 | 1 270 | — |
| Recombination | 47 | 0.86 | 1 600 | 26.0 |
| Across experimental varieties | 7 | 0.95 | 1 770 | 39.4 |
| Medium Composite | | | | |
| All progenies | 538 | 1.32 | 2 460 | — |
| Recombination | 46 | 1.58 | 2 950 | 19.9 |
| Across experimental varieties | 5 | 1.70 | 3 170 | 28.9 |
| Late composite | | | | |
| All progenies | 540 | 1.28 | 2 390 | — |
| Recombination | 35 | 1.62 | 3 020 | 26.4 |
| Across experimental varieties | 7 | 1.79 | 3 340 | 39.7 |
| World Composite | | | | |
| All progenies | 441 | 1.28 | 2 390 | — |
| Recombination | 31 | 1.70 | 3 170 | 32.6 |
| Across experimental varieties | 7 | 1.86 | 3 470 | 45.2 |
| Senegal Dwarf Synthetic | | | | |
| All progenies | 281 | 0.85 | 1 590 | — |
| Recombination | 23 | 1.18 | 2 200 | 38.4 |
| Across experimental varieties | 8 | 1.34 | 2 500 | 57.2 |
| Intervarietal Synthetic | | | | |
| All progenies | 496 | 0.77 | 1 440 | — |
| Recombination | 45 | 0.97 | 1 810 | 25.7 |
| Across experimental varieties | 8 | 1.27 | 2 370 | 64.4 |
| Serere Composite 1 | | | | |
| All progenies | 186 | 1.07 | 2 000 | — |
| Recombination | 24 | 1.38 | 2 570 | 28.9 |

[a] Assumes 70 percent threshing.

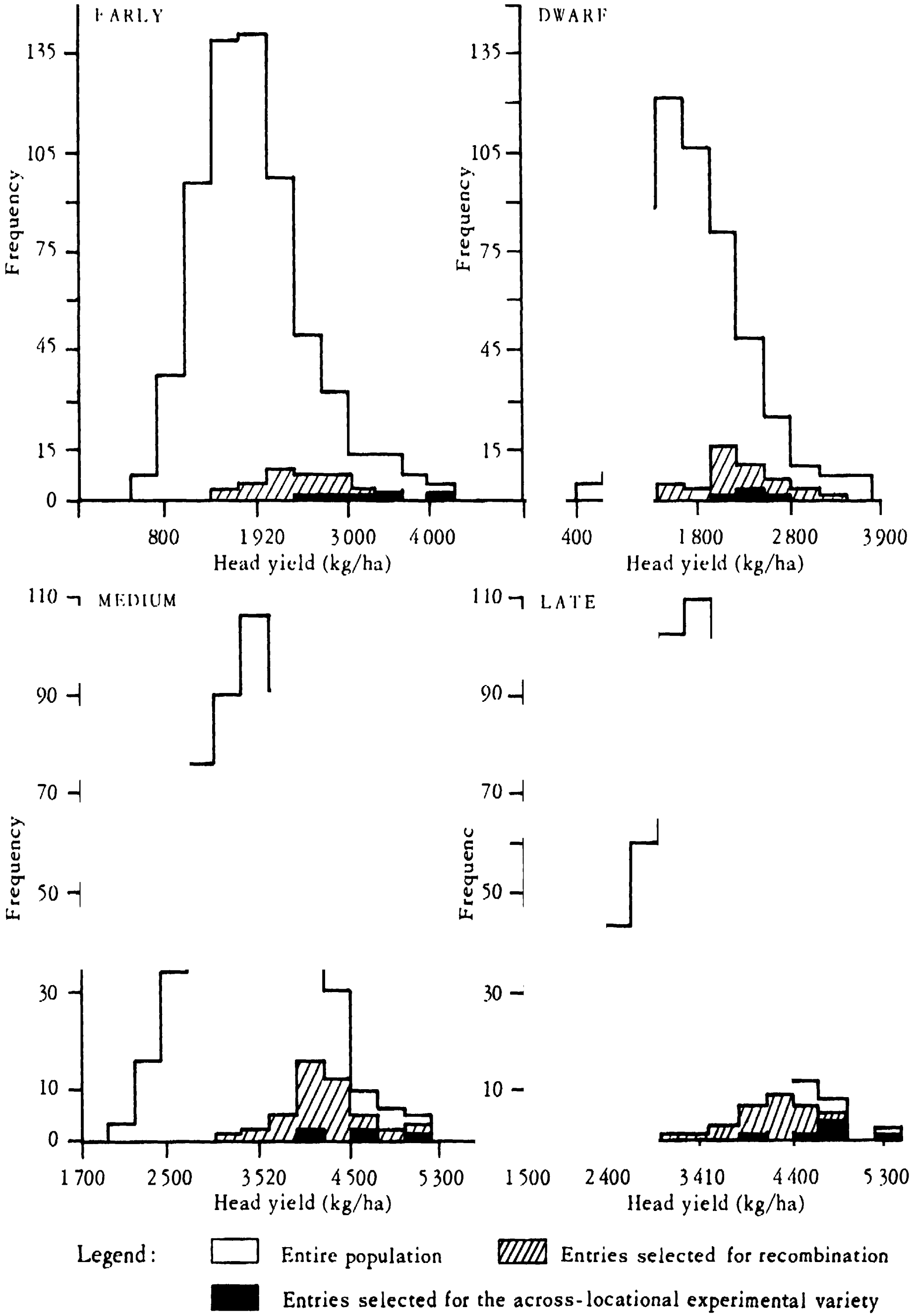
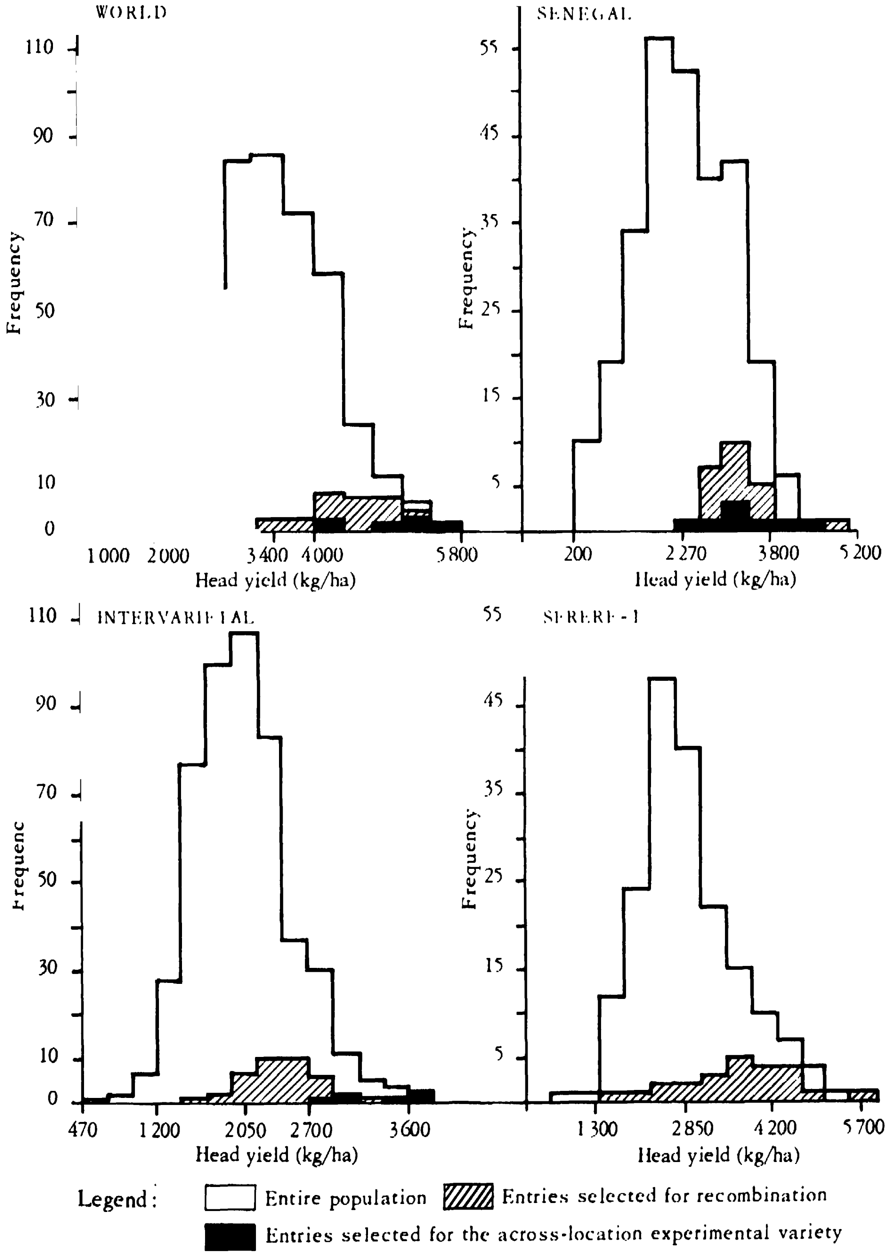



**Figure 11. Histograms for head yield combined over locations for progenies in the Early, Dwarf, Medium, and Late Composite tests, 1975.**




**re 12. Histograms for head yield combined over locations for progenies in the World, Senegal Dwarf, Intervarietal, and Serere Composite tests, 1975.**

**Table 22. Numbers of progeny selected for experimental varieties at various locations where multilocational composite progeny tests were conducted in 1975.**

| | Hissar | Coimba-tore | ICRISAT Center | Saria | Across | RM[a] |
|---|---|---|---|---|---|---|
| Early Composite | 7 | 0 | 0 | NT[b] | 6 | 37 |
| Dwarf Composite | 0 | 0 | 0 | NT | 7 | 47 |
| Medium Composite | 6 | 8 | 0 | 9 | 5 | 46 |
| Late Composite | NT | 8 | 0 | 12 | 7 | 35 |
| World Composite | 8 | 7 | 6 | NT | 7 | 41[c] |
| Senegal Dwarf Synthetic | 0 | 9 | 0 | NT | 8 | 23 |
| Intervarietal Synthetic | 0 | 7 | 0 | NT | 8 | 45 |
| Nigerian Composite[d] | NT | NT | NT | 8 | 0 | 53 |
| Super Serere Composite | 8 | 9 | 0 | NT | 8 | 42 |
| SC 1 (S)4 | 0 | 0 | 0 | NT | 0 | 24 |
| SC 13(M) | 8 | 0 | 0 | — | 0 | — |

[a] RM = total number of progeny selected for recombination

[b] NT = composite not tested at that location

[c] composed of 31 full-sibs and 10 $S_3$'s

[d] only selected entries were sent for testing at Saria

—DBC value (content of basic amino acids)

—restoration/maintenance ability on $A_1$, $A_2$, and $A_3$ systems.

The data gathered so far indicate the existence of an enormous variability for all characters recorded; the data will be processed through the Genetic Resources Communication, Information, and Documentation system of the Taximetrics Laboratory, University of Colorado.

Twenty-five of the working collection entries planted under drought and irrigated conditions during the hot dry season of 1976 showed various forms of resistance to moisture stress.

Large numbers of selfed plants, taken from each of the source populations held under this project (Table 23), have been grown out as head rows ($S_1$'s) to expose and estimate variability. A low selection pressure will be used in recombination. The best $S_1$ rows were crossed to male-sterile lines, and in some cases, $S_2$'s have been taken. For integrating source populations with advanced populations, we shall use specific source population progenies rather than the population as a whole.

Project 4, termed variety crosses and synthetics, uses the more classic approach to continuously produce new variation for selection by crossing inbreds or varieties which complement each other. Single-plant selections are made in the $F_2$, $F_3$, and $F_4$ generations and desirable selections are intercrossed. The products of these crosses will be new inbreds, new restorers or maintainers, entries for synthetics, or composites. Our crossing work has demonstrated that crosses between any of the geographically separate groups (India/East Africa/West Africa) have been productive of good restorers and inbreds.

**Development of new inbreds.** During the year of this report, 1606 variety crosses in four major groups were made. They include:

1. Specific crosses between lines/varieties that have high-yielding capacity and/or which are good for other characteristics such as disease resistance, grain quality, height, head characters, and maturity.
2. Crosses between existing B lines and crosses of established maintainers with those inbreds which give sterile $F_1$'s in the test-cross program.
3. Crosses between known restorers to develop new hybrids which will then provide fertile $F_1$ hybrids more frequently when tested on male-sterile lines.
4. Diallel crosses for making synthetics to test the combining ability of elite inbreds.

In hot dry season 1975, 1006 crosses were made, mostly between known restorers of diverse geographic origins, downy mildew-free inbreds, and maintainers of three cytogenetic male-sterility systems. The $F_1$'s of these crosses were planted during the post-rainy season of 1975 and the $F_2$ populations of most crosses will be grown in rainy season 1976, in some cases split between ICRISAT Center, Hissar, and Bhavanisagar in India, and Nigeria in Africa.

Table 23. **Pearl millet source populations at ICRISAT.**

| Name | Country | Description |
|---|---|---|
| Casady | Uganda and USA | Lines from Uganda originally put into a composite and later recombined with lines from the USA. |
| Dwarf population | Nigeria | Lines from Kano, Nigeria, possessing $D_2$ dwarf gene. |
| Mokwa-maiwa | Nigeria | Mixture of Gero (day-neutral) and Maiwa (photosensitive) landraces. Mass selection for three generations at Mokwa in Nigeria. |
| Maiwa | Nigeria | Population containing photosensitive lines from Nigeria. |
| Ex-Bornu | Nigeria | A Gero landrace selected for yield potential and adaptability from Bornu province in Nigeria. Gridded mass selection for seven generations at Samaru selecting for tillering, cylindrical heads, and reduced height. |

During rainy season 1975, 141 crosses were made between 19 parents; 12 were used in a complete diallel. Performance of the $F_1$'s and parents grown in the following hot dry season will identify entries for a synthetic, and the $F_2$'s will also be grown for selection.

Established maintainers have been crossed amongst themselves and with downy mildew-free inbreds which have given sterile hybrids in the test-cross program. There is an urgent need to develop disease-resistant B lines. Since three systems of fertility restoration seem to operate in pearl millet, we attempted crosses with B lines that maintain the sterility of each of these systems. In addition, selected plants from $F_3$, $F_4$, and $F_5$ progenies were mated to obtain improved inbreds. A total of 459 single and multiple crosses made during post-rainy season 1975 and hot dry season 1976 will be planted in the following rainy season.

During rainy season 1975, 750 $F_4$ progenies were screened at Hissar, ICRISAT Center, and Upper Volta; downy mildew and smut incidence was sufficient at Hissar and in Upper Volta to enable good selection for resistance. Fifty uniform and promising progenies were selected for future breeding work; seed has been supplied to 30 breeders in the SAT and is being tested in an inbred yield trial (PMIT-2) at seven locations in India and one in Nigeria.

During post-rainy season 1975 and hot dry season 1976, an additional 2481 $F_3$, 817 $F_4$, and 428 $F_5$ lines were screened; 46 were considered worthwhile for inclusion in an inbred yield trial (PMIT-1) at four locations.

The best progenies from the variety crosses are used in Project 5 (Hybrids) and also to make synthetics. Three synthetics, labelled 7601, 7602, and 7603, have been produced so far; these will be included in IPMAT-2, the 1976 international adaptation trials. Synthetic 7601 is composed of six outstanding inbreds chosen on *per se* performance. Composite 7602 consists of six parents from a 15 diallel tested in two seasons, while 7603 is a group of seven $D_2$ lines from the population cross Souna $D_2$ × Ex-Bornu.

Also, during the post-rainy and hot dry seasons, nine time and space isolation plots were developed at ICRISAT Center; these were used to produce 17 populations, synthetics, or hybrids for which bulk seed was needed for experiments.

Data on all crosses in Project 4 have been entered into computer files; analysis will be conducted to determine which combinations have been most productive. For future crosses, potential parents will be characterized for a comprehensive list of features, and the computer will be used to select the best complementary single- and multiple-cross combinations to supplement crosses obvious from field observations.

The goal in Project 5 is the development of high-yielding hybrid parents tolerant to diseases and drought. Specific variety crosses are made within female and male parent sources. Other millet breeding projects within the ICRISAT program and the work of breeders elsewhere generate new material with potential as hybrid parents; these are screened also.

Fifty-seven hybrid combinations were divided into three trials on the basis of height and tested during the rainy season of 1975 at ICRISAT Center, Hissar, and Coimbatore, and at Bambey in Senegal. The trial at Coimbatore failed because of drought at emergence. Although not one of the hybrids was totally free of downy mildew, the best ICRISAT combinations outyielded the check (HB-3) by 7 to 61 percent (Table 24).[1] Two of the better hybrids (ICH-42 and ICH-62) were produced by pollinating conventional seed parents with population pollen. Such "variety topcross" hybrids may provide a better solution to disease problems in hybrids than where both parents are inbreds.

ICRISAT hybrids ICH-5 and ICH-45 produced good yields in IPMAT-1.

In trials to date, 12 elite restorers (pollen parents) have been identified, multiplied, and made available to breeders with hybrid programs in which new seed parents are being developed. Two single-cross hybrids (5054 A × B282 and 5054A × 700250) and one variety

[1] Detailed findings of these trials are reported in the ICRISAT publication entitled "Results of the First International Pearl Millet Yield Trials 1975".

topcross (111A × Serere Composite 2) have been supplied to the All India Millet Improvement Project for its 1976 trials.

During the current year, about 4 000 new test crosses were grown and about 30 percent retained for further examination. Sixty-two of these were considered sufficiently promising for inclusion in yield trials at several locations during rainy season 1976. Pollen parents were identified on male-sterile lines 5054A (24 parents), 111A (21), $239D_2A$ (7), and 67A (10); while 7 of the pollen parents variously originated in India, 7 from ICRISAT, 7 from Serere, 30 from Nigeria, 8 from the Indian *Pennisetum* collection, 2 from the United States, and 1 from Bangkok. Of the 30 Nigerian restorers, 15 were identified from progenies of Nigerian composites; the remainder were from the 700-series of segregating breeding lines received from Kano.

Potential male-sterile lines are discovered in the test-cross program. In this way, J104-3 and J2352 were found to be maintainers, and a range of hybrids have been made with the new A lines to test their combining ability in 1976.

A segregated maintainer population derived from 23DB by irradiation and designated 5071 was obtained from the Indian Agricultural Research Institute in New Delhi. This material has been found susceptible to downy mildew

**Table 24. Mean grain yields of the best three entries in three experimental hybrid yield trials at three locations in 1975.**

| Location and Entry | Pedigree | Mean yield (kg/ha) | Yield over HB-3 check (%) |
|---|---|---|---|
| Hissar: | | | |
| ICH-42 | $23D_2A$ × W.C. | 3 630 | 21.9 |
| ICH-13 | 5071A × J 1188 | 3 540 | 18.8 |
| ICH-11 | $23D_2A$ × 700250 | 3 200 | 7.5 |
| ICRISAT Center: | | | |
| ICH-69 | $23D_2A$ × 700251 | 3 690 | 61.0 |
| ICH-35 | $23D_2A$ × 700651 | 3 500 | 52.4 |
| ICH-62 | $23D_2A$ × Serere Composite 3 (M) | 3 390 | 47.7 |
| Bambey, Senegal: | | | |
| ICH-73 | $23D_2A$ × 700516 | 3 780 | 37.9 |
| ICH-45 | $23D_2A$ × 700560 | 3 380 | 23.5 |
| ICH-68 | $23D_2A$ × 700112 | 3 360 | 22.7 |

elsewhere, but three A/B pairs descendant from single-plant selections have so far remained free from downy mildew in the field in rainy season 1975 and in the sick plot in the hot dry season of 1976. The B-lines have been labeled B19-6-2, B23-3-3, and B25-3-3-2.

As noted in Project 4, B lines of different male steriles have been intercrossed in recognition of the critical need for new B lines with resistance to downy mildew. A number of the $F_2$'s are to be grown for this purpose in 1976, where chosen plants will be crossed to appropriate A lines and tested.

The rainy season is the main season for testing yield performance of hybrids and populations. Trials at this time can normally be conducted without irrigation, except for a life-saving irrigation if needed. Broadly, three types of yield trials are conducted in the ICRISAT pearl millet breeding program—

a) Progeny tests ($S_1$'s, $S_2$'s, and full sibs) from the recurrent selection program grown at three to five locations.

b) Experimental hybrid trials conducted at four locations (three in India and one in West Africa).

c) Trials combining entries from (b) above plus populations, synthetics, and coordinated trials conducted at many locations throughout the SAT.

Trials in the last category comprise project 7.

From rainy season 1974 through the hot dry season of 1976, 42 pearl millet improvement trials were conducted by ICRISAT. Eleven have been reported (Annual Report, ICRISAT, 1974-1975).

Of the trials conducted during rainy season 1975, six of four replications each were conducted at ICRISAT Center and in regional nurseries (Table I).

The ten entries in the Populations/Composites trial consisted of four base composites from ICRISAT, one composite from Uganda, two synthetics from Senegal, one synthetic from Hissar, and two hybrids from AICMIP. The high-fertility trial at ICRISAT Center received 100 kg N and 20 kg P per ha; that at Hissar 80 kg N and 40 kg P per ha. The low-fertility trials received 20 kg each of N and P per ha. Plant spacing at Hissar and at the low-fertility trial at ICRISAT Center was 0.5 by 0.10 m; that of the high-fertility trial at ICRISAT Center was 0.75 by 0.10 m. Mean yield of the trial over two locations (the Coimbatore trial was lost because of drought at emergence) under high fertility was 2 230 kg/ha. The three best entries at each location are listed in Table II.

The above results show that both the Serere composite 2(M) and the Medium-base composite can give yields equal to or better than the hybrid check, which produced a yield less than the mean of the trials. Under low-fertility conditions, significant differences between entries did not appear. Mean yield of the low-fertility trial was 790 kg/ha, that of the HB-3 check was 550 kg/ha. The Early composite produced the highest yield, 1 180 kg/ha, followed by the Medium composite with 1 140 kg/ha. In not one

Table I

| Trial | Location | Entries |
|---|---|---|
| Populations/Composites (high fertility) | ICRISAT Center, Hissar, Coimbatore | 10 |
| Populations/Composites (low fertility) | ICRISAT Center | 10 |
| AICMIP trial II | ICRISAT Center | 25 |
| Released hybrids | ICRISAT Center | 12 |

**Table II**

| Location and entry | Grain yield (kg/ha) |
|---|---|
| ICRISAT Center: | |
| Serere Composite 2 (M) | 3 370 |
| Medium Composite | 3 330 |
| Late Composite | 2 710 |
| HB-3 (check) | 2 350 |
| Mean of Trial | 2 350 |
| Hissar: | |
| PHB 10 | 2 720 |
| Serere Composite 2 (M) | 2 490 |
| Medium Composite | 2 280 |
| HB-3 (check) | 1 990 |
| Mean of Trial | 2 010 |

of the three trials did the dwarf populations from Senegal—Senegal Dwarf Synthetic and GAM73—do well.

The Released Hybrids trial, with 12 AICMIP hybrid entries, included four versions of HB-3 (on ms 5071, 5141, 5054, and 5094), HB-4, two versions of HB-5, PHB-10, and PHB-14. Mean yield of the trial was 850 kg/ha. The best entry was HB-3-2 (5141A × J 104) with 1 263 kg/ha. Next was HB-3-3 (5054A × J 104) with 1 189 kg/ha, then came PHB-14 with 1 070 kg/ha, HB-3-4 (5094A × J 104) with 1 050 kg/ha, and HB-5-2 (5141A × K560) with 960 kg/ha. Yields of the latter three entries do not differ significantly. Similar results were observed by AICMIP in a large number of Minikit trials conducted all over India during the rainy season. Downy mildew appeared on all entries except PHB-10 and PHB-14; ergot attack was heavy and all entries were susceptible.

The AICMIP Trial II, consisting of 25 hybrids, was conducted for the AICMIP under rainfed conditions. Mean yield was 987 kg/ha, mean downy mildew and ergot scores were 2.1 and 6.4 respectively, and the mean grain-straw ratio was 0.58. Best hybrids in this trial are listed in Table III.

The highest-yielding hybrid, ICH-11 ($23D_2A$ × 700250) from ICRISAT, was included in this trial to evaluate its performance against AICMIP's hybrids. It was partly susceptible to downy mildew and ergot. NHB-3 (5054A × J 104) was the next highest in yield; differences in yields of the three were not statistically significant.

A single yield trial was conducted under high fertility and irrigation during the hot dry season of 1976. Entries included five ICRISAT hybrids, two Senegalese synthetics, an improved landrace population from Nigeria, and three released hybrids of the AICMIP. ICH-35 was highest in yield; the two Senegalese synthetics and the Ex-Bornu entry yielded less than the

**Table III**

| Entry | Yield | Susceptibility: Downy mildew | Susceptibility: Ergot | Grain /straw ratio |
|---|---|---|---|---|
| | (kg/ha) | (1 - 10)[a] | (1 - 10)[a] | |
| ICH-11 | 1510 | 4.0 | 7.3 | 0.49 |
| NHB-3 (54) | 1480 | 2.0 | 7.5 | 1.06 |
| PHB-24 | 1410 | 2.5 | 6.5 | 0.40 |

[a] Diseases scored on 1 to 10 scale: 1 = free, 10 = highly susceptible

mean yield of the trial (3 060kg/ha) (Table 25). It is perhaps surprising that ICH-5, PHB-14, and Ex-Bornu–top performers in IPMAT-1 –did not do so well in this trial, but conditions during the hot dry season are much different from those of the normal production season.

In the International Cooperation project, seed lots of germplasm, breeding material, and replicated trials were supplied to cooperating scientists or agencies in 25 countries during the year. Visiting scientists were encouraged to make their own selections from ICRISAT fields; seed of the selections was then dispatched to them. Results of trials grown in 1976 have been reported in ICRISAT's publication entitled "Results of the First International Pearl Millet Yield Trials, 1975."

IPMAT-1, the first International Pearl Millet Adaptation Nursery, was sent to 16 locations in 1975. The Nursery consisted of 14 entries, replicated twice, of hybrids, populations, synthetics, landraces, and a local check. The best three entries from the 10 locations from which results have been received are listed in Table IV.

The top performances were given by ICH-5 ($23D_2A$ × Serere-2A), although this hybrid was not adapted to all sites, and by PHB-14. When compared with the hybrids, quite good yields were given by Ex-Bornu (a landrace from Nigeria) and by Serere Composite 3(M). The average grain yield over all locations was 2 300 kg/ha.

**Table 25. Results of the pearl millet yield trial, hot dry season 1976.**

| Entry | Origin | Pedigree | Yield |
|---|---|---|---|
| | | | (kg/ha) |
| ICH 35 | ICRISAT | $23D_2A$ × 700651 | 4 039 |
| HB-3 | AICMIP | 5071A × J 104 | 3 664 |
| ICH-11 | ICRISAT | $23D_2A$ × 700250 | 3 545 |
| HB-4 | AICMIP | 5071A × K 560 | 3 417 |
| ICH-73 | ICRISAT | $23D_2A$ × 700516 | 3 229 |
| ICH-5 | ICRISAT | $23D_2A$ × Serere 2A | 3 170 |
| ICH-44 | ICRISAT | $23D_2A$ × B 282 | 2 933 |
| PHB-14 | AICMIP | 111A × PIB 228 | 2 755 |
| GAM-73 | Senegal | Synthetic | 2 577 |
| Ex-Bornu | Nigeria | Landrace | 2 399 |
| Senegal Dwarf Synthetic | Senegal | Synthetic | 2 330 |
| Mean of trial | | | 3 061 |
| CD at 0.05 level | 6.80 | | |

## Looking Ahead in Pearl Millet Breeding

The population breeding work will expand as further populations come on stream—we expect to fully test 12 populations during the 1976-1977 year. Existing populations will enter the second cycle of testing, and several cooperators in India will be involved. Products from the first cycle of testing (experimental varieties and best progenies) will enter yield trials at several locations, and a limited few will enter IPMAT-2. Additionally, a project to compare the effectiveness of four different methods of selection will commence on one population.

Numerous crosses have now been made between lines that have been developed and tested at ICRISAT since the program started; many of these have been identified as downy mildew resistant by ICRISAT pathologists. These will produce a new wave of segregating material for selection in India and in West Africa.

Testing of new hybrid combinations will continue, since new potential parents are continuously being produced in the population- and variety-crossing projects. Sixty-two new hybrids will go into replicated trials in 1976, while four hybrids from previous trials will be entered in IPMAT-2. For the hybrid program, crosses have specifically been made between restorer (pollen parent) lines and maintainer (B) lines. The latter is especially vital, since a major restriction to the advent of better hybrids is the lack of new B lines.

Preliminary work on screening breeding lines for drought tolerance and seedling vigor indicates that, since a good range of response was demonstrated, these two areas will be remunerative of more intensive studies.

IPMAT-2 will contain 21 entries, contributed from several sources besides ICRISAT. We expect an increase in distribution (50 sets have been made up), with cooperators in Asia, Africa, and South America.

The projected increase in ICRISAT's pearl millet breeding staff in West Africa is expected to add to the effectiveness of the total program, since the inclusion of progeny testing in West African environments will broaden the utility

**Table IV**

| Location | Latitude (°N) | Three highest-yielding entries | | |
|---|---|---|---|---|
| | | First | Second | Third |
| Yei, Sudan | 4 | Serere Comp. 3(M) | Ex-Bornu | Serere Comp. 2(M) |
| Bhavanisagar, India | 11 | ICH-5 | ICH-46 | ICH-44 |
| Kano, Nigeria | 12 | Ex-Bornu | PHB-14 | ICH-46 |
| Maradi, Niger | 13 | IRAT P-1 | Ex-Bornu | ICH-5 |
| Bambey, Senegal | 14 | ICH-45 | ICH-11 | Souna-III |
| Khon Kaen, Thailand | 16 | ICH-5 | PHB-10 | Ex-Bornu |
| Jamnagar, India | 22 | ICH-5 | ICH-11 | ICH-45 |
| Pantnagar, India | 29 | ICH-5 | PHB-14 | ICH-11 |
| Hissar, India | 29 | ICH-5 | ICH-45 | ICH-11 |
| Ludhiana, India | 30 | PHB-14 | Ex-Bornu | Serere Com. 2(M) |

*This earhead exhibits particularly good seed characteristics.*

of the core program and increase the stability of the resultant material.

## Physiology

The Pearl Millet Physiology program is focusing on four plant attributes considered essential for improved and consistent crop performance—(i) high rate of production and efficient distribution of dry matter, (ii) high seed numbers per unit area and high grain-filling rates, (iii) nutrient uptake and distribution capability to support attributes (i) and (ii), and (iv) ability to endure drought stress. For these attributes there is a wide range in genetic variability and genotype × environment interaction. Variability in relation to yield has been studied in order to understand the associations which exist between these attributes. With this approach, source material with superior carbohydrate source and sink attributes, superior nitrogen uptake and distribution, and superior drought resistance may be identified and in turn utilized for genetic improvement.

### Variability in Growth Stages $GS_1$, $GS_2$, and $GS_3$

The variability study on attributes in $GS_1$ (vegetative phase), $GS_2$ (head-development phase), and $GS_3$ (grain-filling phase) on 50 genotypes selected from Indian and African material shows the length of the $GS_1$ may vary from 27 to 39 days (mean for all genotypes: 31.3 days) and the number of leaves expanded may vary from 11 to 14.5 (12.6). The length of $GS_2$ varied from 11 to 39 days (23.5) and the number of leaves expanded varied from 1.5 to 8.5 (4.9). Total number of leaves produced in $GS_1$ and $GS_2$ varied from 13 to 20 (17.4). The largest leaf was generally produced at the time of panicle initiation and its position from the top of the plant varied from 2.3 to 7.8 (5.0) leaves. The length of $GS_3$ varied from 19 to 22 days (20.2). Grain yield varied from 1 352 to 3 739 kg/ha (2 225), corresponding to a variation in grain produced per day per season of 16.3 to 49.9 kg/ha (30.1), and grain per day in $GS_3$ of 67.5 to 187.0 kg/ha (111.0). The contribution to total yield from main heads varied from 33.1 to 98.2 percent (78.0 percent). Seeds per plant varied from 1491 to 5014 (2 502) and mean seed weight varied from 5.2 to 12.3 mg (8.1 mg). Total dry weight produced varied from 6 400 to 21 491 (11 332) kg/ha, corresponding to a variation in seasonal growth rate of 89 to 258 kg/ha per day (151). Harvest index, or percentage of total dry weight of above-ground parts produced as grain, varied from 11.2 to 34.9 (24.7) percent. Analysis of associations between the above variables is in progress.

#### Nitrogen Uptake and Distribution

Fifty genotypes of different background were grown in the hot dry season to measure variability in nitrogen uptake and transfer efficiency to the grain, and to analyze associations between attributes of nitrogen uptake and distribution and carbohydrate source and sink attributes. Nitrogen analysis of plant samples is in progress.

#### Drought-resistance

ifty genotypes, including Indian and African ^terial, were evaluated for their response to a :ss period of 30 days during the $GS_2$, which he most drought-sensitive stage for pearl let. Genotypes were scored as being either *'stant* or *susceptible* to the imposed stress, ed on the following criteria for resistance: absolute yield of at least 2 000 kg/ha under :ss and/or a yield of at least 70 percent of t of the fully irrigated control treatment, ichever is less. The resistant material was :her divided into two different categories ed on the effect of stress on the plant-'elopment cycle: an *avoidant* reaction in ich the developmental cycle continued relatively unaffected during the stress cycle, and a *tolerant* reaction in which the development cycle is interrupted by the stress and resumed only when the stress is relieved. This scoring system was designed to screen material for adaptation to areas with very limited growing seasons in which there is little or no possibility for post-stress recovery (requiring an avoidant reaction to stress) as well as for adaptation to areas with longer growing seasons where there is time for recovery from mid-season drought (in which a tolerant reaction may produce greater yield).

Using these criteria, 1 700 lines and hybrids from the breeding program were screened in the field for their reaction to a 30-day drought stress period beginning at the panicle-initiation stage in hot dry season 1976. Though the results are preliminary, 49 inbreds and 2 hybrids were classed as tolerant, another 49 inbreds and 1 hybrid as avoidant, and 57 inbreds and 18 hybrids as showing a resistance combining both types of reaction. A class of ''avoidant'' genotypes capable of producing a ''second'' yield from new tillers formed during the post-stress recovery period also was identified.

#### Seedling, Root, and Panicle Development

Fifty genotypes were studied in petri dish and field to examine relationships between seed characters and seedling development, and to identify genotypes with seedling vigor. The initial dry weight of the seed was positively correlated to the dry weight of new growth (radicle and plumule) in the petri dish on the fifth day, and in the field at emergence and 7 and 15 days after emergence (r = 0.92-0.94). Based on rate of growth during 15 days in the field, 12 genotypes were found to be better than cv HB-3 check in seedling vigor.

Experiments in growing pearl millet in brick chambers which are then disassembled to permit examination of the root structure indicate that this technique is capable of showing differences in root development, and has a potential for additional evaluations of genotypes. For example, the total number of adventitious roots produced in cvs HB-3 and Mel Zengo at 15, 30, and 45 days were 3, 15, 18 and 4, 17, 27 respectively; the total root length per plant at 45 days was 498 cm in HB-3 and 642 cm in Mel Zengo.

A field study of time reference of morphological and anatomical changes in the panicle components was made on long- (Mel Zengo) and short- (HB-3) panicle genotypes. Length of the $GS_1$, $GS_2$, and $GS_3$ differed between genotypes (28, 13, and 26 days, respectively for Mel Zengo and 31, 23, and 31 days for HB-3), but the mode of development of spikelet meristem, floral parts, and vascular tissue was similar in both. The development of spikelets was acropetal (unlike sorghum, where it is basipetal), whereas anthesis and maturity of grains was basipetal. The time taken to fill the grain increased from top to bottom (19, 23, and 28 days for the top, middle, and bottom grains in HB-3 and 18, 20, and 26 days in Mel Zengo). However, the rate of filling of individual grains decreased from top to bottom (0.46, 0.41, and 0.37 mg./day in HB-3, and 0.66, 0.57, and 0.41 in Mel Zengo).

### Physiological Source Material

Source material for various physiological attributes were identified for use by breeders. These included 23 genotypes with different tillering patterns, 15 genotypes with carbohydrate source and/or sink attributes, and 16 genotypes with drought resistance.

### Looking Ahead In Pearl Millet Physiology

The millet physiology program for 1976-1977 will include a preliminary study of adaptation through crop sampling in the IPMAT nursery grown at three locations in India and a detailed study of genotype differences in nitrogen deficiency over a range of levels of available nitrogen. Screening for drought resistance will continue.

In developmental physiology, it is intended to complete the studies on panicle growth and development, and to continue the studies of seedling vigor and root growth.

## Entomology

For the second year running, entomological problems on pearl millet were minimal and damage was slight. Activities were confined to general surveillance of growing crops of pearl millet and the sowing of one block of HB-3 pearl millet for detailed entomological counts. Forty-five insect species were recorded on the crop; not one attained pest proportions.

*Atherigona approximata* was recorded in low numbers. The maximum attack was found on volunteer plants; a late November 1975 attack affected 1.4 percent of the plants. This fly was also recovered in very low numbers from *Panicum psilopodium*, *Setaria italica*, and sorghum.

Other potentially damaging insects were aphids (affecting 16 percent of the HB-3 planting one month from emergence and then declining); *Chilo partellus* (affecting 2% of stems sampled); and blister beetles of various species, which were reported on up to 50 percent of the heads at flowering.

Millet grown by the breeders in the post-rainy and hot dry seasons 1976 was severely attacked by an as-yet-unidentified mite. It has been previously observed that post-rainy plantings were more liable to attack. The reasons for the attack are probably linked to the spread of maturity in cultivars grown and the extremely favorable conditions for mite development provided by irrigated crops at this season. Early infestation occurs with the appearance of small colonies of mites near the mid-ribs; later the leaves become white and finally dry out completely.

### Looking Ahead in Pearl Millet Entomology

A prime objective of the Entomology unit during the coming year will be the identification of millet germplasm that exhibits superior qualities in terms of pest resistance. Progressively the work will move towards testing of pearl millet lines coming from the breeders and building up levels of resistance in those showing superior agronomic and nutritional quality traits. In connection with cooperative proj rams in other nations, ICRISAT entomologists will be studying the pest spectrum, as well as predators and parasites.

Study of the biology of the main pest species and their seasonal distribution and carry-over in unfavorable climatic conditions will continue. Viruses of the lepidopterous pests will be surveyed, and the work on pheromones of *Chilo partellus* expanded.

Midge biology and the problem of midge screening will also receive attention in the coming year.

# Pathology

The aim of the ICRISAT pearl millet program is to develop sources of high yield potential with good grain quality and broad adaptability, so that yields can be attained and maintained in diverse environments and be relatively stable over seasons. Major factors reducing yields and causing unstable yields in pearl millet include fungal diseases, the most important of which are downy mildew (green ear), caused by *Sclerospora graminicola* (Sacc.) Schroet; ergot, caused by *Claviceps microcephala* (Wallr.) Tul; and smut, caused by *Tolyposporium penicillariae* Bref.

Downy mildew is the top-priority disease because of its great destructive potential within a crop and its ability to flourish in a wide range of environments. It is a major problem almost everywhere pearl millet is grown in the SAT.

Ergot does not occur so regularly nor so widely as downy mildew; it is generally confined to specific locations and seasons where cool wet weather occurs at flowering time. However, ergot is a major reducer of quality in the crop, and has the capacity to render unfit for consumption large quantities of grain.

Smut also is not so widespread as downy mildew in its incidence, but it too causes severe yield-reduction in susceptible lines.

The major objectives of the ICRISAT pearl millet pathology program are to identify sources of broad-spectrum stable resistance to the major diseases and, in cooperation with plant breeders, incorporate this resistance into elite high-yielding materials. The program's main activity is related to screening for resistance, but some work on the biology and epidemiology of the diseases is being undertaken where essential basic information is needed.

## Downy Mildew

### Identification of Sources of Resistance

**At ICRISAT Center.** During 1974-1975 efforts were made to create a hectare-sized sick plot through the repeated raising of a susceptible crop and the incorporation of the resulting infected crop debris into the soil. A limited screening was carried out with 106 lines (inbreds, male steriles, and elite lines from populations). Using a semiquantitative incidence-assessment scale, these lines were evaluated for downy mildew reaction. Nine lines were free from the disease; 52 lines had a disease index of 10 percent or less. In 16 lines, the disease index exceeded 20 percent.

During post-rainy season 1975, experiments with screening techniques utilizing sporangial inoculum demonstrated that infector rows can be efficiently used to provide continuous sporangial inoculum for screening for resistance. Eighty-two lines were screened; of these 14 had no downy mildew and an additional 12 had a severity index of less than 10 percent. Eight susceptible lines recorded more than 75 percent incidence.

**Multilocational testing.** Prior to the establishment of an effective screening system at ICRISAT Center, selection among breeding material for downy mildew reaction had to be done at locations other than the Center. This was because downy-mildew incidence on pearl millet growing at the Center was low and unreliable.

For this reason, a major program was initiated in 1975 to test as much breeding material as possible at two contrasting locations away from the Hyderabad area; locations where effective levels of downy mildew were known to occur. These locations were Hissar,

*The ICRISAT pearl millet program includes an all out effort to overcome the devastating effects of downy mildew disease.*

where 6 ha were planted in cooperation with the Haryana Agricultural University, and at Coimbatore and nearby Bhavanisagar where 5 ha were available through cooperation with the Tamil Nadu Agricultural University. Additionally, ICRISAT's breeder at Saria in Upper Volta, West Africa, planted about 2 ha of breeding material supplied from ICRISAT Center.

The material tested included (i) the working collection, (ii) $F_4$ inbreds, (iii) segregating populations, and (iv) population progeny.

The incidence of downy mildew in these breeding materials during the 1975 trials was reasonably high at Hissar and Coimbatore, high in Saria, but only light at ICRISAT Center.

In the working collection, only 17 of the 340 lines tested were found to remain free of downy mildew at all three sites.

Among the $F_4$ inbreds, 50 lines gave a good performance over locations and recorded low downy mildew incidence. Twelve lines which proved to be restorers with good combining ability on $A_1$ system seed parents recorded zero or low downy mildew scores, and 9 potential B lines (possible seed parents) were relatively free of downy mildew at the Indian locations.

Individual disease-free plants were selected from the segregating populations ($F_2$'s and F bulks) at each location. At Saria, approximately 200 single plants were found entirely free from downy mildew and smut, or with smut present only in trace amounts.

Among the 10 populations, the "World" composite progeny showed the best level and frequency of resistance. This population, along with other favorable characteristics, also shows resistance to rust.

An International Observation Nursery consisting of 13 prominent cultivars plus a local check was distributed to 16 locations in 1975. Over the seven locations which clearly reported on disease, "Ex Bornu" showed the lowest incidence with PHB-14 next. Cultivar HB-3 suffered badly in India and at Kano, moderately at Maradi, but only lightly at Bambey, Senegal.

**The International Pearl Millet Downy Mildew Nursery.** During 1975-1976, in consultation with scientists in national and regional programs in India, Africa, and USA, the IPMDMN (International Pearl Millet Downy Mildew Nursery) was planned and initiated. The IPMDMN program is an international cooperative program which aims to identify sources of broad-spectrum stable resistance to millet diseases, to distribute useful millet germplasm to interested workers, to provide information on the pathogenic variability within pathogen species at different locations, and to act as a communication link between millet pathologists and millet breeders throughout the world.

The 1976 IPMDMN contains 46 entries selected on the basis of results of AICMIP (All India Coordinated Millet Improvement Project), the West African OAU JP-26 project, the ISRA program in Senegal, and ICRISAT trials. The 1976 IPMDMN was sent to 14 cooperators in India, 6 in West Africa (Nigeria, 3; Niger, 1; Upper Volta; 1; Senegal 2), and 2 in Pakistan.

### Studies on Inoculation Methods

During post-rainy season 1975, several inoculation methods, utilizing oospores and sporangia, were compared on a range of test lines. Oospores were applied to the soil, to the seed, or to both just prior to sowing. Sporangial inoculum was provided by scattering infected leaf bits in the plots, by direct inoculation with sporangial suspension sprays, or by the use of infector rows planted in meter-long strips at both ends of the test lines 3 weeks prior to seeding the test lines. Thick bands of maize were sown around each plot to minimize interplot movement of sporangia. Incidence of downy mildew was determined weekly from 3 weeks after the planting of test rows. Data at heading time indicated significant differences between inoculation methods and test lines; lines growing in plots containing infector rows showed the greatest incidence.

### Studies on Seed Transmission

There is conflicting evidence on the subject of internal seed transmission of pearl millet downy mildew. During 1975 critical investigations were initiated to clarify the situation. As externally seed-carried inoculum can probably be eliminated with appropriate fungicidal seed dressings, the key issues became whether the pathogen is internally seed-borne in a viable form, and if it is, whether it is capable of inducing downy mildew in plants raised from such seed.

In order to prove internal transmission of the downy mildew disease, infected plants must be shown to develop from surface-sterilized seed in an environment which excludes the possibility of external inoculum sources, and is at the same time conducive for symptom development.

Beginning in October 1975, seed lots were collected from diseased earheads and from normal earheads on infected plants. These, together with seeds supplied by other workers and thought to contain the pathogen, were surface-sterilized in $H_gCl_2$ (1:1000). More than 800 plants were grown under aseptic conditions in large boiling tubes with growth supported by Hoagland's solution in water agar. Not one developed identifiable downy mildew symptoms. Seedlings grown in the same way and inoculated with sporangial suspensions developed clear systemic symptoms within 6 to 10 days after inoculation, indicating that the boiling-tube environment is conducive for symptom expression. Thus, under the conditions of these experiments, the internal seed transmissibility of pearl millet downy mildew was not confirmed.

In an additional attempt to determine whether the pathogen can be internally seed-borne in a viable form, a series of experiments was set up with several suspect seed lots from ICRISAT Center and from other workers. A technique which promoted callus development under aseptic conditions was employed, the rationale being that if the pathogen is within the seed in a viable form, it will manifest itself on the calli. This study is in progress and is being conducted jointly by staff from ICRISAT, the University of Mysore, and the Indian Agricultural Research Institute at New Delhi. At the time of writing this report, growth of *Sclerospora graminicola* has not been detected on 500 calli maintained in incubators at the ICRISAT Center laboratory. Calli developed from young infected inflorescence tissue under the same conditions developed growth of *S. graminicola*. Complete results of this joint study will be reported later.

**Effect of heat treatments on the viability of pearl millet seed.** Prior to the results of the investigations on the seed-borne nature of pearl millet downy mildew, investigations were made on effects of various wet and dry heat treatments on the viability of pearl millet seed, to determine the practicability of using heat as a possible seed treatment. An HB-3 seed lot was divided into two subsamples, one of which was dried at 40°C for 48 hours. Both dried and nondried subsamples were subjected to wet heat at 55°C (for 0, 10, 20, 30, 60, 120, and 180 min) and dry heat at 80°C (for 0, 1, 2, 4, and 6 hr). This sample of pearl millet seed withstood up to 30 minutes of wet heat at 55°C and up to 2 hours of dry heat at 80°C without major loss of viability.

**Fungicide treatment of seed and soil.** One possible means of reducing the degree of incidence of downy mildew in a crop of a susceptible cultivar is to dress the seed with a contact fungicide in order to kill externally seed-borne oospores, and a systemic fungicide which could kill within the tissues the invading mycelia resulting from infection by soil-borne inoculum. Prior to conducting such a test in the field, laboratory investigations of the effect of two candidate fungicides on the viability and vigor of seed and seedlings were conducted. The fungicides Agrosan and chloroneb were used singly and in combination at rates from 2 g formulation/kg seed to 10 g formulation/kg seed. Viability of treated seed was tested in petri plate-moist chambers and seedling vigor was studied on seedlings growing on Hoagland's-water-agar (50% Hoagland's solution, 0.7% agar). The results indicate that a combination of the fungicides at up to 10 g each/kg seed has no detrimental effect on seed viability, but there were marked effects on seedling vigor when combined at rates in excess of 2 g each/kg.

In preliminary pot trials with the fungicide Dowco-269 used as a soil drench at 300 ppm, downy-mildew incidence in young plants of cv Tift 23-A was reduced from 59 percent in the check to 6 percent when drenched at planting and again a week later.

## Ergot

During rainy season 1975, 3222 lines were screened for ergot resistance under artificial epiphytotic conditions. Of these, 446 lines showed no ergot development and 219 lines had less than 100 sclerotia per head. These lines will be retested during rainy season 1976.

Studies on the biology and epidemiology of ergot—including the source(s) of primary inoculum, means and source of secondary infection, infection site and path to the ovary, and relationship between pollination and susceptibility—are in progress. This information is necessary to the development of sound control measures.

**Table 26. Basic amino acids and DBC values of 14 pearl millet samples analyzed at ICRISAT, 1975-1976.**

| Sample | Protein | Basic amino acids in protein | Lysine in protein | Lysine in sample | DBC (80 mg P) | Chemical score[a] |
|---|---|---|---|---|---|---|
| | (%) | (g/100 g) | (g/100 g) | (g/100 g) | | |
| 1 | 18.0 | 5.0 | 1.6 | 0.29 | 25 | 29 |
| 2 | 18.2 | 8.8 | 2.5 | 0.55 | 25 | 45 |
| 3 | 16.8 | 9.1 | 2.6 | 0.44 | 26 | 47 |
| 4 | 11.3 | 9.3 | 2.7 | 0.30 | 27 | 49 |
| 5 | 17.1 | 9.3 | 2.6 | 0.43 | 27 | 47 |
| 6 | 14.5 | 9.5 | 2.9 | 0.42 | 29 | 53 |
| 7 | 14.2 | 9.5 | 2.9 | 0.41 | 27 | 53 |
| 8 | 12.2 | 10.6 | 3.3 | 0.41 | 29 | 60 |
| 9 | 10.2 | 10.7 | 3.5 | 0.36 | 31 | 64 |
| 10 | 7.3 | 11.3 | 3.9 | 0.29 | 36 | 71 |
| 11 | 10.7 | 11.8 | 3.6 | 0.38 | 38 | 65 |
| 12 | 7.6 | 12.4 | 4.2 | 0.32 | 36 | 76 |
| 13 | 7.1 | 13.3 | 5.4 | 0.39 | 37 | 98 |
| 14 | 5.1 | 15.2 | 5.7 | 0.29 | - | 103 |

[a] Based on the lysine content (55 mg/g) of reference protein taken as 100 percent (FAO/WHO, 1973).

## Smut

Preliminary studies indicate that inoculation of plants in boot stage with smut-spore suspension gives good smut infection. This method will be used to screen lines for smut resistance during the 1976-1977 year.

### Looking Ahead in Pearl Millet Pathology

In the work with downy mildew, the position regarding seed transmission will be clarified and procedures recommended for introduction of seed through plant quarantine. The role of sporangia in the epidemiology of the disease will be rechecked. Several thousand lines will be screened for downy mildew resistance, using the 'infector row' system in field disease nurseries. Most of the 1976 IPMDMN trials, including those in West Africa, will be visited.

In the work with ergot, the 665 lines with little or no ergot selected in 1975 will be checked for resistance during the rainy season of 1976. Relationships between fertilization and susceptibility will be examined.

Smut inoculation techniques found effective during hot dry season 1975 will be tested for effectiveness during rainy season 1976.

Rust-resistant lines selected during 1974 and 1975 will be tested for rust reaction during the rainy season at the Bhavanisagar station in southern India.

# Grain Quality

In this project we are mainly concentrating on protein and lysine content and seed size in addition to visual appearance. From September 1975 to February 1976, 1714 samples were analyzed in the biochemistry laboratory.

A preliminary result of analysis is shown in Table 26. Fourteen samples were analyzed for protein; lysine and DBC values were also obtained. Protein percentage in the 14 samples ranged from 5.1 to 18.2 percent, while total basic amino acids and lysine showed a range from 5 to 15.2 and 1.6 to 4.7 g/100 g protein, respectively. Lysine as percent of sample showed a range from 0.29 to 0.55 and the DBC values ranged from 25 to 38. Chemical scores calculated on the basis of FAO/WHO (1973) recommendations varied between 29 and 103, indicating the existence of a wide range in lysine content of protein in pearl millet samples.

It is known that protein content is markedly affected by season, location, fertility level of the soil, and many other biological and environmental factors (Table 27).

Protein content varied from 7.9 to 12.6 percent and did not seem to be influenced by yield levels. Likewise a marked difference up to 6.5 percent was found in protein values in the Working Collection entries planted during the post-rainy and rainy seasons. The mean protein range has been between 10 and 11 percent, which equals or exceeds that of other cereals–such as maize, rice, and sorghum.

Composite test progenies seem to offer a wide range of protein content and seed weight. Protein contents in the World Composite and Senegal Dwarf Synthetic are shown in Table V.

From the results obtained so far, it appears that composite progenies and the Working Collection offer scope for isolating high-protein lines.

## Microbiology

Fifty-seven lines of pearl millet and related species were grown during the post-rainy and hot dry seasons under low-fertility conditions (20 kg N, 9 kg P fertilizer/ha); the nitrogenase activity associated with their roots were

**Table 27. Seasonal variation in pearl millet cv HB-3 grain yields and protein content.**

| Season | Trial and Location | | Protein (%) | Yield (kg/ha) |
|---|---|---|---|---|
| Post-rainy 1974 | Demonstration | | 7.9 | 1 270 |
| | Hybrid trial I | ICRISAT Center | 8.5 | 1 130 |
| | Hybrid trial II | ICRISAT Center | 9.5 | 1 960 |
| Hot dry 1975 | Demonstration | | 8.3 | 730 |
| Rainy 1975 | Hybrid trial I | ICRISAT Center | 10.2 | 2 150 |
| | | Hissar | 12.6 | 2 850 |
| | Hybrid trial II | ICRISAT Center | 10.2 | 1 570 |
| | | Hissar | 10.7 | 2 000 |
| | Hybrid trial III | ICRISAT Center | 10.4 | 2 320 |
| | | Hissar | 10.8 | 2 230 |
| | Population trial | ICRISAT Center | 10.7 | 2 350 |
| | | Hissar | 12.1 | 1 990 |

Table V

| Season | Composite | Progeny | Samples | Protein Range | Content Mean |
|---|---|---|---|---|---|
| | | | (No) | (%) | (%) |
| Rainy 1974 | World Composite | $S_1$ | 200 | 7.9-19.1 | 12.29 |
| Rainy 1975 | World Composite | $S_1^a$ | 83 | 7.5-15.0 | 11.13 |
| | Senegal Dwarf Synthetic | $S_1$ | 278 | 8.1-15.3 | 11.45 |

[a] Derived from $S_1$'s of 1974

assayed by acetylene reduction. The roots were washed to remove soil and incubated under about 1 percent $O_2$ in nitrogen or argon gas, or cores (15 cm in diameter) of soil with roots were incubated under air. Little activity was obtained before the $GS_2$ growth stage. Up to nine-fold differences between lines were obtained on a given assay day, but there were also large (up to 20-fold) differences between plants of the same line. The reason why some plants of the same line were much more active than others is not clear, but the variation was observed with both assay methods. Excised roots reduced acetylene at the rate of up to 1.9 μmol/g dry root per hour, or 5 μmol/plant per hour. In the core assay, roots in moist soil were more active than in dry soil, with up to 1.8 umol acetylene reduced/core per hour or 1.1 umol/g dry root per hour. Nitrogenase activity continued during the grain-filling and -maturing stages until leaf senescence became marked.

A lag phase occurs before the onset of much cetylene reduction by excised roots. To educe the multiplication of nitrogen-fixing rganisms during this period, roots collected in e afternoon were stored under argon at 15°C efore assaying for acetylene reduction at om temperature (30 to 35°C) the next day.

Nitrogen-fixing organisms of the *Spirillum oferum* type were isolated from roots with uch nitrogenase activity; the roots had been rface sterilized for 2 minutes in 0.1% merric chloride. A larger variety of organisms grew when unsterilized root pieces were placed in the nitrogen-free malate medium.

**Looking Ahead in Pearl Millet Microbiology**

ICRISAT microbiologists plan to measure the amounts of nitrogen fixed by root-associated bacteria, and determine the contribution of this nitrogen fixation to nitrogen uptake by the plant. The technique of using $^{15}$N labeled $NO_3$ and $N_2$ will be employed for this work. Relationships between the reduction of acetylene and the reduction of nitrogen by root associations will also be studied, as will the influence of fertilizer applications on nitrogen fixation in millets. Identification of bacteria involved in such fixation will also begin.

## Agronomy

The response of pearl millet to phosphorus, use of supplemental water, weed management, and various aspects of intercropping was studied.

Phosphorus applications have generally produced an economic yield increase in pearl millet; sorghum, however, produces a greater response.

Application of supplemental water to pearl millet has not always produced significant results. However, after a 30-day dry period in one experiment, a response of 770 kg of grain/ha was obtained from a single 5-cm irrigation—a practical increase when considered in regard to the runoff harvested in the catchment area.

Weeds can cause a yield reduction of up to 70 percent in pearl millet. The most critical period, in terms of weed competition, is the third to sixth week after planting. Pearl millet is susceptible to many herbicides, and careful screening under several soil types will be necessary to determine the safety of herbicides.

Previous intercroppings of pearl millet with pigeonpea have provided a 40 to 83 percent gross economic gain when compared to growing the crops separately on the same areas. When comparing the competitive effects of various crops in pigeonpea-intercrop mixtures, pearl millet was found to depress pigeonpea yields more than did sorghum, soybean, and Setaria.

### Looking Ahead in Pearl Millet Agronomy

In 1976, 40 pearl millet lines will be screened for their intercropping behavior in standard varieties of pigeonpea, sorghum, and Setaria. In a second experiment, the competitive effects of four contrasting varieties each of millet and sorghum will be measured.

# ΓHE PULSES

## ıgeonpea *(Cajanus cajan)*

## :hickpea *(Cicer arietinum)*

rain legumes are expected to play increasing les in providing adequate protein in the diets the underfed of the SAT. Chickpea, third-nking of the world's pulses, is now planted on me 10.5 million hectares throughout 10 itions in the SAT. Pigeonpea plantings proach 3 million hectares. Both crops are ilized as human food, and are of vital impor-nce to millions of persons in areas where crop oduction is erratic or otherwise limited. Both ve high contents of protein—18 to 24 percent d more—and contain some amino acids not und in cereals. When combined with rice, rghum, millet, or wheat, chickpea and geonpea provide an adequate balanced otein-calorie diet.

When compared with many of the world's major crops, the work of the scientist with chickpea and pigeonpea is just beginning. Hopefully breeders of these pulses will benefit from the experiences with other agricultural species and will be able to make rapid head-way. The concentrated effort as initiated by ICRISAT is long overdue.

### ICRISAT Goals

ICRISAT pursues two broad goals regarding pigeonpea and chickpea:

Assembly, maintenance, and screening of the world's germplasm resources, including worldwide search for new strains and related species and the provision of seed from the ICRISAT collection for evaluation and use in programs of colleagues everywhere.

To increase, through breeding, the ability of genotypes to produce higher yields, optimum protein content and quality, and characteristics favored by the consumer.

In its management of the germplasm collections and genotypes resulting from its work, ICRISAT intends to continue its cooperation with plant breeders in all national and regional pulse-improvement programs, hoping to provide superior genetic materials for the use of others who are attempting to develop tailor-made lines needed for conditions in a specific location. The segregating of genotypes with a wide diversity of genetic characters, plant architecture, physiological attributes, and insect and disease resistance is a major goal.

## ICRISAT Center

ICRISAT Center is the major research facility of the Institute. Located near the village of Patancheru, the facility includes two major soil types found in the semi-arid tropics. The red soil is light and droughty; the black soils have a great water-holding capacity. The availability of these two soil types provides an opportunity to conduct selection work under conditions representative of many areas of the SAT. Three distinct agricultural seasons—rainy, post-rainy, and hot dry—characterize the area. The rainy season, also known as monsoon or kharif, usually begins in June and runs into September; more than 80 percent of the annual rainfall occurs during these months. The post-rainy season of October through January, also known as post-monsoon or rabi, is dry and cool; days are short. From February until the rains begin again is known as the hot dry season, with daily temperatures of between 36° and 43°C.

Chickpeas are planted in October or November and grow on residual soil moisture; only one generation per year is grown. June and July are the months in which pigeonpeas are planted; they grow throughout the season and on into the post-rainy season without irrigation. An additional generation of early maturing types is planted at ICRISAT Center in December and grown with irrigation so as to provide an additional generation for the breeding program.

# PIGEONPEA

[redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

# Pigeonpea

Increased production of pigeonpea through breeding can be accomplished by incorporating high-yield potential, resistance to disease, and either resistance to insects or adaptation to insect-management systems (chemical control, escape) in new genotypes. First priority is to develop types for existing production systems (companion cropping, low inputs); radical changes for new systems (sole cropping, intensive insect control, mechanized production) is a longer-term objective. A wide range of pigeonpea germplasm, as well as that of related species, is being used as source material in a program designed to provide superior breeding material for national programs.

## ɜermplasm

### ˸ollection

ɈIew introductions, exchanges with other ·eeders in India and other countries, rear-ngement of mixed collections, and collec-ɔns made in India have increased the ˸RISAT pigeonpea germplasm to 5 530 ˸cessions, an increase from 3 964 at the end of e 1974-1975 ICRISAT year. Entries in stock ·e listed in Table 28.

A total of 1 692 accessions were sown during .iny season 1975. These consisted of 195 lines ɔtained from various institutions in India and ɔroad, 273 lines from collection trips made by ˸RISAT scientists, and 1 238 accessions om which insufficient details could be ɔtained during the 1974-1975 year.

### ɩploration

systematic collection of pigeonpea in the ates of Karnataka, Orissa, Bihar, and parts of ndhra Pradesh provided 305 new entries. The ɩaterial collected from the tribal area of ndhra Pradesh and Orissa has features ɩtherto unavailable, including an unusual seed ɔrm similar to cowpea. Seed size of pigeonpea in the tribal areas is large; this year's collection contains a sample weighing 24.5 g/100 seeds.

### Evaluation

Systematic evaluations of the accessions sown were made. In addition to observations

**Table 28. Pigeonpea germplasm lines at ICRISAT Center.**

| Country of origin | Entries |
|---|---|
| | (no) |
| Australia | 13 |
| Bangladesh | 19 |
| Brazil | 7 |
| Burma | 24 |
| Colombia | 5 |
| Dominican Republic | 6 |
| France (Versailles and Gaudeloupe) | 19 |
| Ghana | 1 |
| Guyana | 4 |
| India | 4 989 |
| Indonesia | 1 |
| Jamaica | 11 |
| Madagascar | 1 |
| Mexico | 2 |
| Nigeria | 19 |
| Pakistan | 2 |
| Peru | 3 |
| Puerto Rico | 40 |
| Senegal | 10 |
| Sri Lanka | 54 |
| Thailand | 2 |
| Trinidad | 37 |
| USA | 2 |
| Others (unknown) | 259 |
| | 5 530 |

recorded previously (Annual Report, ICRISAT, 1974-1975), harvest index, shelling percentage, number of primary and secondary branches, number of racemes, and number of pods per plant were observed. Also, leaf area and specific leaf weight of 100 accessions was recorded. The range in data observed on various characteristics is presented in Table 29.

Perenniality is an inherent characteristic in pigeonpea. All entries planted during rainy season 1975, except the early cultivars, are being evaluated for their perenniality and ratoonability. All lines were hand-picked and two ratooning systems were applied—no pruning, and pruning of the stems to about one meter in height.

Sample data of 300 lines were processed at the Taximetric Laboratory, University of Colorado, USA; this provides a base for the germplasm catalog.

A total of 2 583 samples were supplied to 16 breeders or institutions in India. An additional 1 145 samples were supplied to other countries (Bangladesh 35, China 10, France 101, Kenya 6, Laos 45, Nigeria 136, Philippines 410, Sri Lanka 65, Sudan 53, Tanzania 45, Thailand 6, Trinidad 89, Upper Volta 44, and USA 100).

**Atylosia**

Two new species of *Atylosia* were collected from the southern hills of Tamil Nadu. Details on *Atylosia* germplasm are presented in Table 30.

Interspecific crosses were attempted among the five available species of *Atylosia*. A few crossed seeds have been obtained from the reciprocal crosses between *A. platycarpa* × *A. scarabaeoides* and *A. sericea* × *A. scarabaeoides*. The crossed seed will be planted in pots during rainy season 1976.

For wild *Atylosia* sp. the Nilgiri Hills, Palni Hills, and Tirupati/Tirumala Hills were searched, and the species *A. trinervia* (*A. can-*

**Table 29. Range in characteristics of pigeonpea cultivars grown at ICRISAT Center, 1974-1975 and 1975-1976.**

| Character | 1974-1975 minimum | 1974-1975 maximum | 1975-1976 minimum | 1975-1976 maximum |
|---|---|---|---|---|
| Time to 50% flowering (days) | 60 | 177 | 60 | 177 |
| Time to 75% maturing (days) | 118 | 250 | 120 | 245 |
| Plant height (cm) | 110 | 305 | 60 | 235 |
| Primary branches (no) | — | — | 6.0 | 27.37 |
| Secondary branches (no) | — | — | 3.0 | 76.67 |
| Racemes per plant (no) | — | — | 21.33 | 470.33 |
| Pods per plant (no) | — | — | 16.33 | 993.67 |
| Seeds per pod (no) | 3.0 | 6.4 | 2.6 | 5.7 |
| Yield per plant (g) | — | — | 2.53 | 167.92 |
| Harvest index | — | — | 3.96 | 51.22 |
| Shelling percent | — | — | 29.34 | 78.55 |
| Seed size (g/100 seeds) | 5.58 | 17.36 | 4.01 | 21.80 |
| Leaf area ($cm^2$) | — | — | 12.98 | 93.51 |
| Specific leaf wt ($mg/cm^2$) | | | 4.03 | 11.05 |
| Protein (%) | 19.1 | 28.6 | — | — |

*dollei)* and *A. albicans* were added to the collection, as were a few related genera and species. A search for *A. cajanifolia* in the Puri forests of Orissa was unsuccessful.

### Looking Ahead in Pigeonpea Germplasm

Collecting expeditions for wild *Atylosia* spp. are planned for Assam, Meghalaya, Sikkim, Himachal Pradesh, Tamil Nadu, Kerala, the western Ghats, and the Puri forests in Orissa. Some locations in India which yielded few or no entries in earlier expeditions will be revisited, with special attention to hilly and tribal areas. Drought-resistant material on red shallow soil is doing very well there. The collection is still deficient in lines of non-Indian origin and efforts to obtain these will continue. Southeast Asian and some African countries will be searched, even where areas under cultivation are reported to be few.

Revision of *Atylosia* and *Cajanus* will be undertaken to resolve taxonomic and nomenclature problems. Historical geographical distribution of the species will be summarized, and current distribution information will be pdated.

To study the perennial nature of pigeonpea, trial of 4 years' duration will be initiated. orty-five entries from improved cultivars and ermplasm will be chosen to compare yields fter one, two, three, and four seasons of rowth. After each season, production from atooned plants will be compared with that of he newly sown crop. Ratooning experiments uring rainy and post-rainy seasons 1976 will ield information on the ratoonability of a large umber of accessions.

Initial screening on insect attack and resisance will be carried out on the entire germlasm collection by the Entomology section. ne Pathology section will continue screening r resistance to sterility mosaic and wilt.

## reeding

ne unusually high rainfall in the extended iny season 1975 profoundly affected the pigeonpea-breeding program. Continuous wet conditions in September resulted in severe insect damage to early maturing types, so the seed crop was produced by the second flush. Plant damage from waterlogging was common, leading to difficulties in selection and crossing, and loss of precision in replicated trials.

On the positive side, genetic differences in response to waterlogging was observed. Selection for resistance, or tolerance, was automatic in a number of segregating populations (Fig 13). In the rainy season 1976, check cultivars, $F_2$ and $F_1$ populations will be included in a program for continued selection for tolerance. Such tolerance would contribute to the stability of yield over locations and seasons.

Selection for superior types from the germplasm continued. Based on individual plant performance, 339 lines were planted in two-row plots, with a check cultivar after each 10 plots. In spite of adverse conditions, comparison of test entries and nearby checks is considered valid. Selection pressure applied to 122 medium-maturity lines chosen for measurement can be quantified as in Table 1.

These 32 lines will be yield-tested under four environments at ICRISAT Center and by Andhra Pradesh Agricultural University at four additional locations. They will be tested

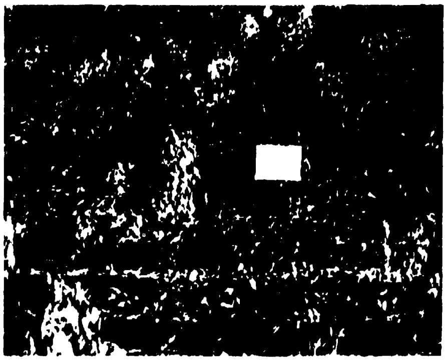


*Figure 13. Differential response to waterlogging in the $F_2$ population of the pigeonpea cross 73052.*

**Table 30. Atylosia species in the ICRISAT collection.**

| Species | Origin | Collector | Remarks | Samples |
|---|---|---|---|---|
| *Atylosia albicans* | Kodaikanal | van der Maesen | Climber | 1 |
| " | Bangalore | " | | 1 |
| " | Tirupathi | " | | 1 |
| " | Chamundi hills | " | | 1 |
| *Atylosia trinervia* | Kundah (Tamil Nadu) | " | Bush | 1 |
| *Atylosia volubilis* | Hundru Falls, Ranchi | " | Climber | 1 |
| *Atylosia lineata* | Mahabaleshwar | " | Bush | 1 |
| " | Bhor | " | " | 1 |
| " | Poona, W.Ghats | " | " | 2 |
| *Atylosia platycarpa* | Lucknow | L.J. Reddy | Climber | 1 |
| *Atylosia scarabaeoides* | Poona | van der Maesen | " | 1 |
| " | Bangalore | " | " | 1 |
| " | Srisailam | " | " | 1 |
| " | Kandava, Bihar | " | " | 1 |
| " | Panposh, Bihar | " | " | 1 |
| " | ICRISAT site | " | " | 1 |
| " | Hayatnagar | A.N. Murthi | " | 1 |
| " | Jangalapalli | van der Maesen & A.N. Murthi | " | 1 |
| *Atylosia sericea* | Mahabaleshwar | van der Maesen | Bush | 1 |
| " | Poona, W. Ghats | " | " | 1 |

Table I

Medium maturity group:

| | (No) | Yield (% of check) |
|---|---|---|
| Lines grown | 122 | 109.2 |
| Lines selected | 32 | 157.1 |
| Selection differential | 26% | 47.9 |

for disease and insect reaction in separate plantings.

In the later-maturity group, 27 lines were selected for further testing at higher latitudes. This material will upgrade available parent material, and some of it may be directly usable by local programs.

Hybridization of contrasting parent lines was continued, with 429 topcrosses, 65 double crosses, and 30 triple crosses completed. Single-plant selections were made in 32 $F_2$'s, 319 $F_3$ progenies (18 crosses), and some early and medium selections were advanced in a December planting. With major emphasis on developing breeding material for diverse environments, 62 $F_2$'s and 5 $F_3$'s were increased in bulk with mild negative or no selection.

Comparison of 25 genotypes in pure stand with sorghum companion crop indicated differential cultivar response and, though not conclusive, the data suggest the desirability of selecting under companion-cropping conditions. Some promising $F_2$ and $F_3$ populations will be grown with maize intercrop during rainy season 1976.

Exploitation of the perennial nature of pigeonpea was tried by cutting plants above branching, yet below the pod-bearing, level at harvest. This permitted rapid regrowth and development of a second crop on the ratooned plants. The feasibility of obtaining an additional crop was demonstrated, and differences in ratoonability among varieties were observed. Listed (Table II) are results with four cultivars adapted to the Hyderabad area, which illustrate the difference in production in the second crop. Under conditions where a second grain crop is not possible, cutting high at harvest will encourage regrowth for grazing. Final harvest of the four cultivars was on 4 April 1976.

The day-length reaction of pigeonpea cultivars is obviously related to maturity, and more work is needed to understand the relationship of the two factors. Observations at Mahabaleshwar, Maharashtra (lat 17°N, elev 7000 feet), indicated that under long-day conditions low temperatures could trigger flowering in normally short-day types. Monthly plantings at Hyderabad (lat 17°N, elev 1700 feet)

Table II

| Cultivar | Normal crop (first harvest) | | Ratoon crop (final harvest) | | |
|---|---|---|---|---|---|
| | time until harvest | yield | time until harvest | yield | Total yield |
| | (days) | (kg/ha) | (days) | (kg/ha) | (kg/ha) |
| BDN-1 | 173 | 1466 | 100 | 898 | 2364 |
| No 148 | 168 | 1304 | 115 | 838 | 2142 |
| PM-1 | 173 | 1072 | 110 | 488 | 1560 |
| Hy-4 | 160 | 1088 | 123 | 431 | 1519 |

differentiated four photoperiod-response groups among 21 cultivars (Fig 14). Observations from the international adaptation trials at different latitudes showed a profound effect on plant size resulting from early flower initiation at the lower latitudes. Screening of genotypes under 15-hour day length (longer than natural day length in the tropics) showed the following lines to be insensitive: Pant A-1, Pant A-2, Baigani, UPAS 120, Prabhat, 3D 8126, and Hy-1, as well as some segregates from crosses of *Cajanus* × *Atylosia lineata* and *C.* × *A. scarabaeoides*.

The inheritance of photoperiod response was studied in one cross planted in February; the results indicate that a single gene, dominant for short-day requirement, controlled the flowering reaction. In the same cross, planted in the normal season, segregation for flowering date indicated complex inheritance of maturity period.

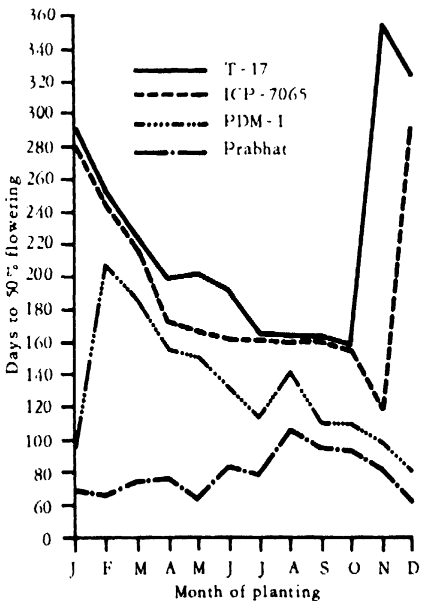



**Figure 14. Flowering-response groups of pigeonpea varieties in monthly plantings at ICRISAT Center (lat 17°N).**

Work will be continued to categorize parents in the breeding program, and to evaluate the possible usefulness of photoinsensitivity in later-maturity types.

Among the types found in the germplasm with markedly reduced pod set, one had normal flower morphology but produced no pollen (Fig 15). This male sterility has been found to be controlled by a single recessive gene, and it is being transferred to a number of agronomically desirable lines.

*Figure 15. Simply inherited genetic male sterile in which flowers are completely normal except for absence of pollen shown in three buds on left. Normal flowers are on right.*

Studies were carried out on the simulation of insect activity on flowers. Treatments were tripping (release of the reproductive column from the keel petals), tripping combined with crossing to ensure pollination, and control. Results have indicated that a higher percentage of pod setting was obtained when the flowers were manipulated by hand as compared to those permitted to develop without disturbance.

Hand manipulation increased the percent pod set in tripping and tripping combined with cross-pollination treatments with or without bagging (i.e. without or with insect activity, Fig

16). The number of seeds per pod also increased significantly with the simulation of insect activity (from 2.57 to 2.88 seeds per pod).

From breeding material generated during the year, 1 668 individual plant selections; 85 $F_2$, 17 $F_3$, and 5 $F_4$ bulks; and 21 double cross $F_1$'s were furnished to 27 breeders in national programs.

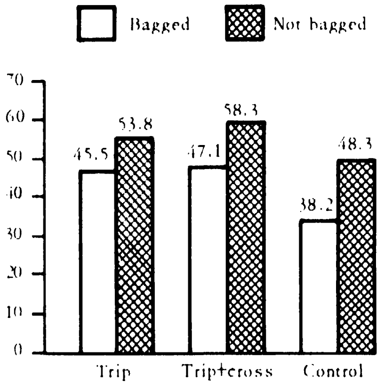



**Figure 16. Pod setting in flowers manipulated to simulate insect activity in pigeonpea.**

### Looking Ahead in Pigeonpea Breeding

Evaluation of $F_4$ and $F_5$ lines in rainy season 1976 will provide the first quantitative estimates of genetic gains in the selection program. Observed results will influence objectives and approaches in subsequent selections.

Photoperiod, duration period, temperature regime, and other less-obvious factors, plus all their interactions, tend to create location-specific adaptation of pigeonpea cultivars. Additional emphasis on initial breeding and selection under diverse environments is needed; plans for provision of this facility are under development.

Increasing emphasis will be on selection for factors influencing stability of yield—resistance to wilt and sterility mosaic, resistance to waterlogging, and adaptation to soils with high salt concentrations.

## Physiology

Experiments on several aspects of the physiology of pigeonpea were conducted in the field.

### Nitrogen Uptake and Distribution

The uptake and distribution of nitrogen in the shoot system was investigated throughout the growing season with nodulated plants to which no fertilizer had been supplied. The absolute amounts of nitrogen in cv ICRISAT-1 grown on black soil are plotted in Figure 17. The continued uptake of nitrogen at a high rate during the reproductive period is particularly interesting, especially in its contrast with the pattern found in chickpea (page 129). During this period, there was a remobilization of nitrogen from stems and leaves into the reproduc-

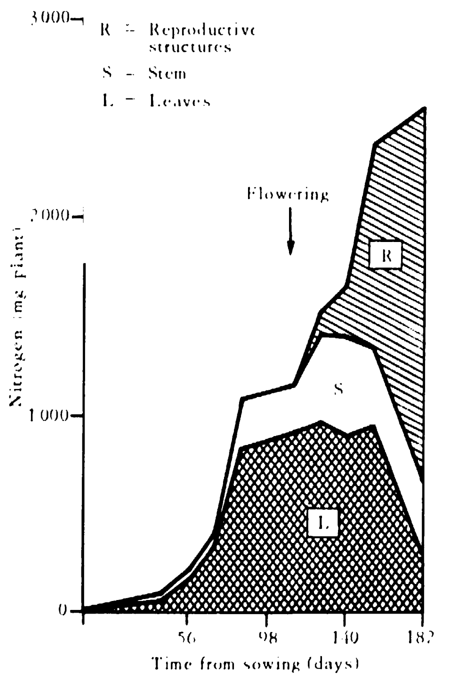



**Figure 17. Nitrogen content and distribution throughout the growing season in pigeonpea plants of cv ICRISAT-1 growing on black soil.**

tive structures. In other pigeonpea cultivars, the pattern was similar.

At the time of harvest of the medium-duration cultivars ST-1, ICRISAT-1 and Hy-3C grown in monoculture, about 2200 kg/ha of plant debris (mainly fallen leaves) was left on the soil. The average nitrogen content was 1.4 percent; thus about 31 kg/ha of nitrogen in this form was returned to the soil.

**Detailed Analysis of Yield Components**

Pods were collected nodewise from the branches of several cultivars of pigeonpea and the number of pods per node, number of seeds per pod, and hundred-seed weight determined. Data for cv ICRISAT-1 are plotted in Figure 18. A very similar pattern was noted in the other cultivars. The interesting feature of these

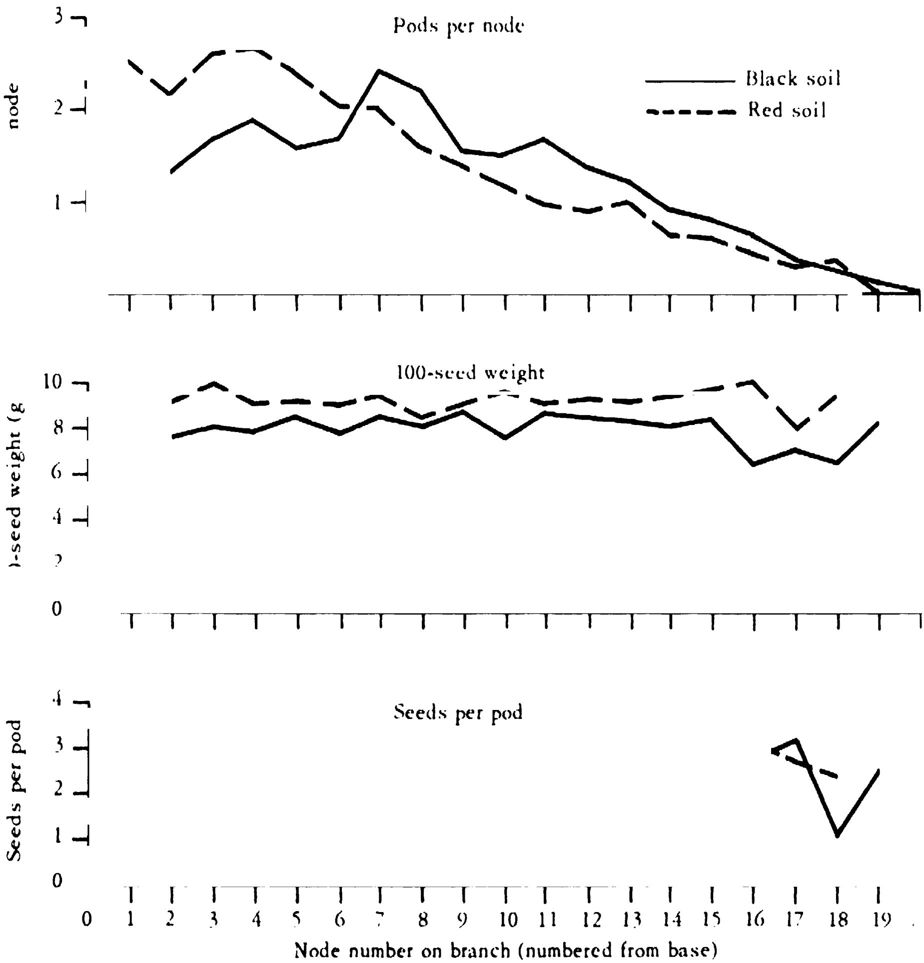



**Figure 18. Nodewise analysis of yield within branches (average of 30 branches) of pigeonpea ICRISAT-1.**

observations is that although progressively fewer pods develop on younger, more apical nodes, these later-formed apical pods show no systematic decline in number of seeds per pod or 100-seed weight. This is in striking contrast to the pattern found in chickpea (page 130), and suggests that the development of the later-formed pods does not take place under conditions of limiting nutrient or assimilate supplies.

## Effects of Experimental Defoliation on Yield and Yield Components

The effects on yield of partial and complete defoliation at the time of flowering were investigated with plants grown in the rainy season (Jun plantings), post-rainy season (Nov plantings), and off season (Jan plantings).

In the three early cultivars (Prabhat, Pant A-2, and T-21) and two medium-duration cultivars (ST-1 and Hy-3C) grown in red and in black soils during the rainy season, results were similar—the yield was reduced roughly in proportion to the degree of defoliation. The reduction in yield was due to the reduced number of pods per plant; number of seeds per pod and hundred-seed weight were more or less unaffected (Fig 19).

Preliminary experiments on a range of long-duration cultivars grown in the normal (rainy) season and on two early cultivars grown in the off season showed a rather different pattern; in these cases, although total defoliation led to a large reduction in yield, 50-percent defoliation had little or no effect on yield when compared with the controls. Average number of seeds per pod and 100-seed weight remained more or less constant in all treatments.

In the post-rainy season the average reduction in yield brought about by 50-percent defoliation of five cultivars was 15 percent. Again this reduction was owing to a reduction in number of pods per plant; other yield components were unaffected.

The most striking feature of these results is that the defoliation treatments affected only the number of pods per plant, and not the number of seeds per pod or the 100-seed weight. When taken in conjunction with data

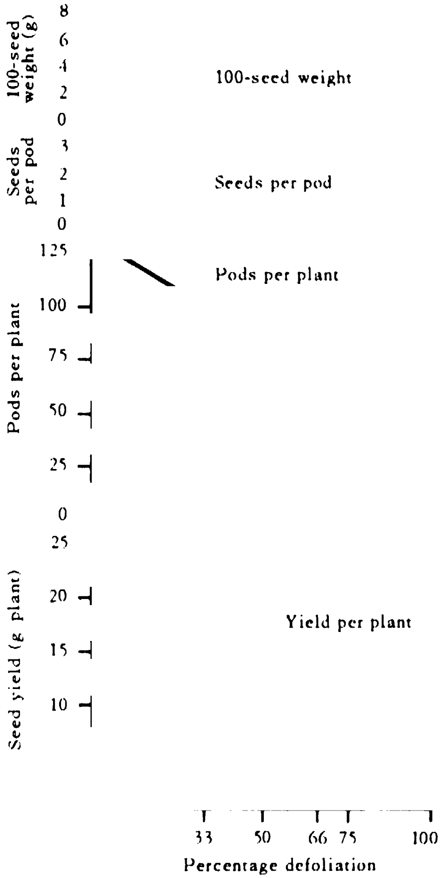



**Figure 19. Effect of defoliation on yield and yield components of pigeonpea cv T-21 grown on red soil during rainy season 1975.**

presented in Figure 18, these findings suggest that the plants have some mechanism whereby the number of pods set is less than or equal to the plants' ability to fill the pods completely; if more pods were set than the plants were able to fill, there would be a reduction in the average number of seeds per pod or in the 100-seed weight. In the normal season, at least in the early and medium-duration cultivars, the internal factors determining pod-set appear to be related to the leaf area of the plant; the simplest explanation would be in terms of the supply of photoassimilates. However, in situations where 50 percent of the leaves could be removed with little or no reduction in yield, the supply of photoassimilates from the leaves may not have been the primary factor determining pod-set and yield.

### Effects of Experimentally Delayed Pod-set

Under natural conditions, flowers or pods may be lost or damaged as a result of pest attacks or unfavorable weather. The ability of the plants to compensate by increased pod-set from later-formed flowers was investigated experimentally by removing flowers at regular intervals for up to 6 weeks. This experiment was carried out with two determinate and two indeterminate early cultivars and one medium-duration cultivar grown on red and on black soils. In general, the longer the period that pod-set was prevented, the greater was the reduction in yield, but in some cases yield reductions were quite small. In cv ST-1 grown on red soil, for example, continuous flower removal for 6 weeks led to a reduction in yield of only 22 percent. An examination of the pattern of pod-set on the racemes showed that the plants compensated for the loss of the earlier-formed flowers by setting pods from the later-formed flowers at the more apical nodes of the racemes. With continuation of flower removal, the racemes continued to grow and produce additional flowers. A similar pattern was found in all cultivars (Fig 20).

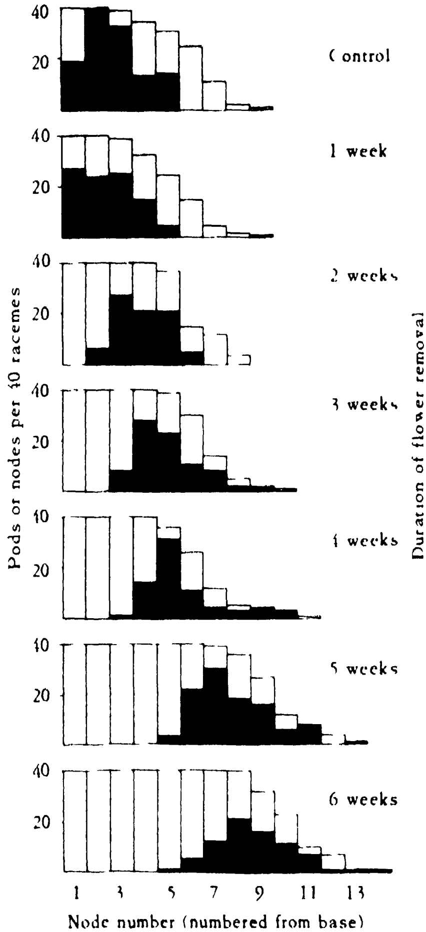



**Figure 20. Effect of flower removal for different periods on the pattern of pod-set on racemes of pigeonpea cv ST-1 grown on red soil.**

### Some Physiological Aspects of Wilt Disease

The wilt disease usually strikes pigeonpea during the plant's reproductive phase. In an off-season crop where 30 to 40 percent of the plants were dying of wilt, it was found that in plants where pod development was prevented by repeated removal of flowers, less than 1 percent developed wilt symptoms. This suggests that the entry or development of the pathogen may have taken place because of a reduced supply of assimilates to the roots caused by competition from the developing pods. The assimilate supply to the roots during the reproductive phase might be expected to be reduced further by removal of the leaves. In plants from which some or all of the leaves were removed during the normal season, there was indeed a striking increase in the incidence of wilt disease; the greater the degree of defoliation, the higher the incidence of wilt. Results were similar on red and black soil alike. In an experiment carried out in conjunction with the Pulse Pathology section, plants ratooned after the first harvest were defoliated at the time they were flowering and podding; again the incidence of *Fusarium* wilt was much higher in the defoliated plants (42%) than in the controls (4%).

### A Harmful Residual Effect of Pigeonpea

In red and black soils, sorghum and pigeonpea were planted where pigeonpea had been growing during the previous year (rainy season 1974). The growth of the sorghum was normal, but that of the pigeonpea was severely reduced in regions exactly corresponding to the previous plots. In the early stages, there was a general yellowing of the affected plants and a loss of the lower leaves. Final yields of both early and medium-duration cultivars were reduced by 70 to 80 percent. The symptoms were not relieved by additional fertilizer applications, nor could an explanation in terms of pests or pathogens be found. The possibilities that these effects are caused by nematodes or are allelopathic—i.e., caused by a toxic factor or factors released into the soil by the previous year's pigeonpea crop or its residues—are being investigated.

### Effects of Seed Size on Growth and Yield

Pigeonpea seedlings which develop from large seeds are larger and grow faster than seedlings developing from small seeds. In order to investigate whether these differences would persist and cause differences in yield, trials were established on red and on black soil comparing ungraded, large, and small seeds of cvs ST-1 and Hy-3C. There was no significant effect of seed-grading on yield.

### Pigeonpea as a Post-rainy Season Crop

A post-rainy season crop of pigeonpea was sown on black soil in November, using cultivars of different maturity groups. In this season, under short days, the duration of the photosensitive 'medium' and 'late' cultivars was much reduced, although the relative order of duration was not affected. The highest yields (430 kg/ha) were obtained with the cultivar of longest duration. Higher yields were obtained with populations of 222 000 plants per hectare than with 133 000 plants per hectare.

### Looking Ahead in Pigeonpea Physiology

The main factors limiting grain yield will be investigated, in hopes of identifying varietal differences in characters which could, in combination, lead to increased yields. In collaboration with the Microbiology section, we hope to find out more about the fixation and uptake of nitrogen. Varietal differences in response to spacings, including the wide row-to-row spacings often found in intercropping systems, will be studied. In relation to the exploitation of the perennial nature of the crop, experiments on the effects of different times and methods of ratooning on the second and subsequent harvests of grain and fodder will be conducted. Additional studies are planned for determining potential of pigeonpea grown at high plant populations during the post-rainy season.

## Entomology

Priority areas for entomology research were identified this year. A list of identified and fully authenticated pests of pigeonpea has been developed. Surveys at ICRISAT Center and in farmers' fields in Andhra Pradesh and neighboring states has elucidated levels of damage and relative importance of the main pest species. Work on the biology of the main pulse-pest species intensified, and considerable success was obtained in developing satisfactory field-screening techniques for pest-resistance studies. Collaborative work with the AICPIP (All India Coordinated Pulses Improvement Project) was initiated, and preliminary trials on pesticidal control were started. Some work on the use of vegetable oils for control of insect pests was initiated.

**Pigeonpea Pests**

More than 120 insect species, 100 known to be agricultural pests, have been identified at ICRISAT Center. Significant findings follow.

1) *Heliothis armigera* (Hubner) is a major, and probably the most important, pest of pigeonpea at ICRISAT Center and in all other areas sampled. This noctuid moth was also noted to be a severe pest of the crop of Kenya.

2) Two species of plume moth, *Exelastis atomosa* Wals. and *Sphenarches anisodactylus* Wals., are present at ICRISAT Center. The former is active on the crop throughout the year, but the latter is present only in the cooler (post-rainy season) months, November to January. The moths are of moderate importance with regard to crop loss.

3) Two agromyzid flies are important pests of pigeonpea. *Melanagromyza obtusa* Mall. is a severe pest, particularly on late-maturing cultivars, and is particularly common and active in the cooler months. Parasitism was high (17.4%) in December 1975. The other fly, *Ophiomyia centrosematis* de Meijere, causes damage to stems of young seedlings.

4) There is a broad spectrum of lepidopterous pod borers which range in severity and occurrence seasonally. They include *Maruca testulalis* Geyr., *Etiella zinckenella* Trts., *Adisura stigmatica* Warr., and *A marginalis* Walk; *Maruca* was particularly common in the wetter-than-usual rainy season 1975.

5) Although the leaf tiers, *Eucosma critica* Meyr. and *Cydia ptychora* Meyr., cause easily discernible damage to young pigeonpea leaves, and can affect flowers and pods, their effects on yields are apparently slight. Parasitism levels on the former species were high (13.8%) in January.

6) A new pest hymenopteran, *Taraostigmodes* sp., was found. This pest causes some damage to young pods of late-maturing cultivars. It is of considerable potential importance in situations where ratoon crops are grown. Laboratory observations have confirmed it to be a primary pest.

7) Although there is a diverse spectrum of hemipterous pests, their significance in terms of damage has not been studied. Common species are *Clavigrella scutellaris* (Westw.), *C. horrens* Doh., *Nezara viridula* L. *Eurostylus* sp., *Campylomma livida* Reut, *Calcoris* sp., and *Dolicoris indicus* S.

8) Severe damage to flowers can be caused by *Megalurothrips usitatus* Bagnall, *Ceuthorrhynchus asperulus* Fist., and various meloids, especially *Mylabris pustulata* Thunb.

**Pest Biology**

Life cycles of *H. armigera* were drawn up for all months of the year (Table 31).

Development was slower in the cooler months of December, January, and February. In the laboratory, nine generations were completed in one year. Field studies revealed high levels of parasitism (up to 13.3%) of larvae. Parasites recovered from various pests, including *H. armigera*, are listed in Table 32.

Details of oviposition by all pest-moth species are being gathered, both in the field and in the laboratory. The oviposition record showed a maximum of 1 458 eggs by *H. armigera*, 140 eggs by *E. atomosa*, and 135 by *M. testulalis*.

**Crop-loss Studies**

Critical evaluation of insect numbers, sources of crop damage, and final yields were made on a series of trials at ICRISAT Center and for pod damage on extensive samples collected from farmers' fields in Andhra Pradesh, Bihar, Karnataka, Orissa, and Maharashtra.

Data show that pigeonpea produces an excess of buds and flowers and much of the shedding is due to causes other than insects. Damage by insects was higher on black-soil than on red-soil areas. Considerable progress was made in characterizing damage by various pest species. Counts showed that plants with a clustering habit (determinate types) were more

**Table 31. Life cycles of *Heliothis armigera* Hub bred on pigeonpea in the laboratory, July 1975-May 1976.**

| | | Duration of stage | | | | | |
|---|---|---|---|---|---|---|---|
| | | Egg | | Larvae | | Pupa | | Total |
| | | (days) | | (days) | | (days) | | (days) |
| Jul | 1975 | 9-10 | | — | | — | | — |
| | Mean | 9.5 | (1 120)[a] | | | | | |
| Aug | 1975 | 3-9 | | 15-32 | | 9-30 | | 27-71 |
| | Mean | 5.5 | (15 992) | 22.2 | (238) | 9.8 | (99) | 37.5 |
| Sep | 1975 | 2-5 | | 12-23 | | 8-17 | | 22-45 |
| | Mean | 3.4 | (15 732) | 17.6 | (119) | 12.9 | (294) | 33.9 |
| Oct | 1975 | 3-4 | | 13-22 | | 11-17 | | 27-43 |
| | Mean | 3.6 | (15 234) | 16.8 | (446) | 12.1 | (275) | 32.5 |
| Nov | 1975 | 3-5 | | 18-25 | | 11-21 | | 32-51 |
| | Mean | 4.4 | (6 789) | 22.1 | (232) | 15.6 | (47) | 42.1 |
| Dec | 1975 | 4-6 | | 22-33 | | 17-27 | | 43-66 |
| | Mean | 5.3 | (5 499) | 27.7 | (109) | 21.3 | (220) | 54.3 |
| Jan | 1976 | 3-7 | | 25-39 | | 21-29 | | 49-75 |
| | Mean | 4.7 | (8 998) | 31.5 | (128) | 25.6 | (81) | 61.8 |
| Feb | 1976 | 3-8 | | 24-38 | | 18-23 | | 45-69 |
| | Mean | 5.0 | (6 184) | 34.6 | (73) | 20.8 | (33) | 60.4 |
| Mar | 1976 | 2-4 | | 16-28 | | 11-16 | | 29-48 |
| | Mean | 3.3 | (10 910) | 20.5 | (89) | 13.4 | (204) | 37.2 |
| Apr | 1976 | 2-3 | | 13-23 | | 8-12 | | 23-38 |
| | Mean | 2.3 | (6 907) | 16.5 | (205) | 10.1 | (196) | 28.9 |
| May | 1976 | 2-3 | | 13-21 | | 7-11 | | 22-35 |
| | Mean | 2.4 | (2 422) | 15.5 | (109) | 9.0 | (102) | 26.9 |

[a]( ) Numbers observed

**Table 32. Parasites and predators of various pests of pigeonpea recorded at ICRISAT Center.**

| Host | Parasites | Predators |
|---|---|---|
| 1. *Heliothis armigera* | *Goniopthalmus halli* Mes.<br>*Sturmiopsis inferens*. Tns<br>*Ichneumon sp.*<br>*Metopius rufus* Cameron<br>*Compoletis chloridae Uchida*<br>*Diadegma sp.*<br>*Xanthopimpla stemmator* Thunberg<br>*Enicospilus sp.* nr. *zyzzus* Chiu<br>*Pelexorista solennis* Walk. (Heliothis on cowpea)<br>*Carcelia (senometoria) illota* Curran<br>*Hexamermis albicans* Sieb. (Nematode) | 1. *Ropalidia marginata* Lepeltier<br>2. *Delta companiforme esuriens* F |
| 2. *Exelastis atomosa* | *Diadegma sp.*<br>*Apanteles paludicolae* Cam. | |
| 3. *Maruca testulalis* | *Phanerotoma hendercasisella* Cam. | |
| 4. *Eucosma critica* | *Apanteles sp.*<br>*Paralitomastix varicornis* (Nees)<br>*Hexamermis albicans* Sieb. | |
| 5. *Taraostigmodes sp.* | *Paraholapsis sp.* | |
| 6. *Lampides boeticus* | *Hesperencyrtus lycoenephila* (Risbec)<br>*Hexamermis albicans* Sieb. | |
| 7. *Clavigrella sp.* | *Paraholapsis sp.* | |
| 8. *Callosobruchus sp.* | *Gryon sp.** | |
| 9. *Oxyrachis sp.* | *Centrodora sp.* nr. *mumtazi* * Hayat | |

* Egg parasites

severely attacked by borers than were indeterminate types (Table 33). Damage levels, particularly in early and mid-maturing types where podding coincided with borer population peaks, could be extremely high—up to 90 percent. It was demonstrated that pest status was affected considerably by maturity groups. The pod fly, *M. obtusa*, was relatively much more important in late-maturity cultivars. However, with all types, lepidopterous pod borers were the principal source of yield loss. Calculation of percentage potential seed loss indicated that in unsprayed conditions 37 and 82 percent of the crop was lost.

Data obtained from general observations on pest levels, maturity class, and growth habit was checked in an experiment grown on red and on black soils with six cultivars of different maturity groups, three of which were still segregating for growth habit. Data on the determinate (segregating) cultivars (Table 34) fully support earlier conclusions.

Survey data (Table 35) confirmed that insects were a serious limiting factor on yield in all districts. There was no doubt that *H. armigera* was the main pest; *E. atomosa*, *M. obtusa*, and *M. testulalis* were also important sources of loss.

**Control measures.** In view of the severe losses and the probable difficulty of locating sources of resistance to *H. armigera*, some work on insecticidal control was carried out. An objective was to determine the minimum number of sprays to be applied and to determine the most-effective timing of applications. The determinate cultivar Pusa Ageti was used. Marked and significant reductions in pest numbers were obtained with sprays. Although overall yields were low because of prolonged and heavy rains, significant increases in yield were obtained. Use of endosulfan, along with the linking of spray regimes to production of young fruiting forms, were significant factors in preventing excessive loss (Table 36).

**Pollination studies.** Studies of pigeonpea pollination by bees were initiated with the assistance of specialists of the Rothamstead Exper-

**Table 33. Effect of growth habit and maturity of pigeonpea on insect damage under unsprayed conditions (average of three cultivars).**

| Maturity/ growth habit | ICRISAT cultivar No. | Cause of pod damage borers | podfly | Hymenopteran |
|---|---|---|---|---|
| | | (%) | (%) | (%) |
| Early maturity | | | | |
| Determinate | 7170, 7169, 7220 | 76.3 | 1.4 | 2.3 |
| Indeterminate | 1115, 7179, 7018 | 46.0 | 3.0 | 2.5 |
| Mid-maturity | | | | |
| Determinate | 7050, 7243, 3868 | 76.9 | 3.2 | 0.6 |
| Indeterminate | 7222, 22, 2627 | 72.3 | 3.5 | 0.6 |
| Late maturity | | | | |
| Determinate | 7051, 6295, 6943 | 55.0 | 13.4 | 3.6 |
| Indeterminate | 6613, 7119, 6883 | 53.3 | 16.3 | 4.9 |
| L.S.D. (.05) | | 15.24 | 5.01 | 2.95 |

*An ICRISAT scientist discusses pest damage of pigeonpea with members of the Technical Advisory Committee of CGIAR.*

iment Station, UK. A detailed list of flower visitors was drawn up, and studies were conducted on the effect and frequency of bee visits. An attempt to measure the magnitude of outcrossing—using an obtuse leaf-marker gene—failed, since it was discovered that different bees were attracted to the "normal" and "obtuse" types. Megachilidae were very numerous on the former and *Apis dorsata* on the latter. Megachilids (10 species), Xylocopids (13 species), and one species of *A. dorsata* were all important in pollen transfer on the crop. A notable absentee was *A. cerana*, the domestic honeybee of Asia.

**Screening techniques.** Development of methods for increasing lepidopterous borer attack in the field progressed during the year. Levels of up to 90 percent damage by pest species were obtained when a system using interlards of a mixture of susceptible cultivars of mixed maturity was used. In collaboration with the AICPIP 50 cultivars with a wide range of general interest, along with a small amount of material with some indications of tolerance to borers, were tested. In the former group, some cultivars—notably Hy-3C, Hy-4, PS-71, C-11, SA-1, Pant A-2, Pant A-3, and Prabhat—were found to produce very low yields (less than 100 kg/ha) in comparison with others (160 to 170 kg/ha). In the latter group, no lines were found to be completely resistant, but borer attack varies from 29 to 73 percent and pod fly from 4 to 20 percent, indicating variability in susceptibility. This is encouraging from the standpoint of further studies.

Table 54. Pest damage on determinate and indeterminate cultivars of segregating populations of different maturities planted in 1975 on red and on black soils at ICRISAT Center and grown under unsprayed conditions.

| Cultivar | Growth habit | Date 50% flowering | Pod maturity (70%) | Total pods | Pod damage by borers | Pod damage by podfly | Pod damage by *Taraostigmod* sp. |
|---|---|---|---|---|---|---|---|
| | | | (days) | (no/40 plants) | (%) | (%) | (%) |
| a) Trial on Red Soil | | | | | | | |
| Pusa Ageti (IC.28) | Determinate (Early) | 10 Sep | 139 | 3017 | 64.5 | 10.2 | 0.3 |
| | Segregating Indeterminate | | | 8953 | 25.9 | 8.2 | 3.6 |
| Collection from Madhya Pradesh (IC-7050) | Determinate (Mid) | 20 Nov | 190 | 11259 | 23.3 | 13.5 | 2.3 |
| | Segregating Indeterminate | | | 17582 | 12.1 | 28.1 | 4.1 |
| Khandwa-154-1 | Determinate (Late) | 26 Nov | 244 | 3242 | 25.4 | 14.8 | 10.8 |
| | Segregating Indeterminate | | | 8047 | 15.5 | 32.0 | 20.8 |
| b) Trial on black soil | | | | | | | |
| Pusa Ageti(IC.28) | Determinate (Early) | 18 Oct | 160 | 5221 | 72.2 | 1.2 | 0.4 |
| | Segregating Indeterminate | | | 8086 | 41.9 | 2.8 | 0.5 |
| Collection from Madhya Pradesh | Determinate (Mid) | 6 Dec | 228 | 5431 | 49.0 | 9.9 | 2.9 |
| | Segregating Indeterminate | | | 13511 | 21.1 | 25.5 | 4.9 |
| Khandwa-154-1 (IC-6365) | Determinate (Late) | 8 Dec | 246 | 4750 | 42.9 | 21.0 | 5.0 |
| | Segregating Indeterminate | | | 8449 | 27.1 | 33.3 | 4.1 |

Table 35. Pod and seed damage in pigeonpea samples collected from various locations of Andhra Pradesh, 1975-1976.

| Location | Percentage of pods damaged (means) | | | | Actual Pods damaged | Percentage of seeds damaged (means) | | | | | Actual seed loss (of seed potential) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Borers[a] | Podfly | Bruchids[b] | Hymenopteran | | Borers[a] | Podfly | Bruchids[b] | Hymenopteran | Ill-formed | |
| | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) |
| Adilabad | 33.2 | 4.6 | 1.2 | 0.4 | 37.8 | 16.0 | 3.8 | 1.5 | 0.4 | 8.4 | 28.8 |
| Nizamabad | 18.2 | 14.6 | 1.2 | 0 | 32.8 | 8.6 | 12.9 | 1.0 | 0 | 12.5 | 34.3 |
| Karimnagar | 39.0 | 8.5 | 1.4 | 0.1 | 45.6 | 23.8 | 4.6 | 1.1 | 0.1 | 4.0 | 32.4 |
| Warangal | 53.4 | 8.8 | 7.1 | 0.03 | 60.1 | 28.1 | 5.6 | 5.2 | 0.03 | 3.1 | 36.9 |
| Medak | 58.5 | 5.4 | 0.5 | 0.3 | 61.9 | 34.0 | 5.5 | 1.4 | 0.2 | 6.9 | 46.6 |
| Hyderabad | 39.2 | 6.6 | 0.8 | 0.9 | 45.6 | 22.8 | 6.3 | 0.7 | 1.1 | 7.6 | 37.8 |
| Nalgonda | 48.9 | 6.6 | 0.8 | 1.4 | 57.0 | 25.3 | 6.5 | 0.9 | 1.1 | 15.2 | 48.0 |
| Khammam | 40.8 | 2.3 | 0.8 | 0 | 41.8 | 14.4 | 0.4 | 1.1 | – | 12.2 | 27.0 |
| Mahboobnagar | 24.4 | 4.2 | 1.0 | 0.3 | 28.2 | 11.1 | 2.3 | 0.7 | 0.2 | 5.8 | 19.5 |
| Kurnool | 67.9 | 3.2 | 0.4 | 1.7 | 71.4 | 47.7 | 2.2 | 1.0 | 1.2 | 8.3 | 59.3 |
| Anantapur | 55.4 | 3.0 | 1.1 | 0.4 | 59.1 | 37.9 | 2.8 | 1.9 | 0.9 | 7.5 | 59.0 |
| Cuddapah | 39.1 | 3.8 | 0.4 | 1.1 | 43.7 | 20.1 | 5.1 | 0.3 | 0.7 | 35.2 | 61.1 |
| Prakasam | 43.6 | 1.3 | 0 | 0.1 | 44.8 | 24.7 | 1.4 | 0 | 0.1 | 40.8 | 72.0 |
| Guntur | 50.0 | 3.4 | 0.2 | 1.5 | 53.8 | 31.2 | 3.8 | 0.5 | 0.8 | 27.7 | 63.5 |
| Krishna | 22.7 | 1.1 | 1.6 | 0 | 23.5 | 10.7 | 0.4 | 2.0 | – | 14.6 | 25.7 |
| West Godavari | 17.4 | 1.3 | 1.4 | 0 | 18.7 | 7.7 | 0.8 | 1.5 | – | 11.0 | 19.5 |
| East Godavari | 37.3 | 1.9 | 4.3 | 0 | 38.8 | 14.7 | 0.9 | 4.6 | – | 13.3 | 29.0 |
| Vishakhapatnam | 15.3 | 2.8 | 22.2 | 0.3 | 18.2 | 13.5 | 2.5 | 14.6 | 0.5 | 28.9 | 26.1 |
| Srikakulam | 20.8 | 1.9 | 15.5 | 34.3 | 54.7 | 4.6 | 0.7 | 26.4 | 30.6 | 9.0 | 44.9 |

Includes bruchid-damaged pods and seeds (assessed in Jan 1976)

sessed 8 weeks after sampling (Mar 1976)

**Table 36. Insecticidal control of pests on early determinate-type pigeonpea (*Pusa Ageti*) BT$_4$ planted on 14 July 1975. Date of 50-percent flowering: 11 October 1975. Days to maturity: 156.**

| Schedules | percent pod damage | | | | Calculated seed Loss | Yield/plot | Calculated yield |
|---|---|---|---|---|---|---|---|
| | Total | by Borer | by Pod fly | by Hymenopteran | | | |
| | (%) | (%) | (%) | (%) | (%) | (g/100 m$^2$) | (kg/ha) |
| I. Fixed schedule (according to phenology of plants, 5 sprays) | 13.1 | 11.5 | 1.2 | 0.5 | 16.2 | 4 909.5 | 491.00 |
| II. Heavy spraying (weekly, 11 sprays) | 9.2 | 7.0 | 1.4 | 0.8 | 13.9 | 4 107.5 | 410.75 |
| III. Sprays based on entomological counts (5 sprays) | 16.7 | 13.5 | 2.3 | 0.9 | 15.4 | 3 214.5 | 321.45 |
| IV. Unsprayed (check) | 29.9 | 24.0 | 4.9 | 1.3 | 21.6 | 2 106.5 | 210.65 |
| SE of mean ± | = 0.88 | | | | | 529.4 | |
| Significance | = H.S. | | | | | S | |
| CV (%) | = 10.2 | | | | | 29.54 | |
| LSD at 0.05 | = 2.8 | | | | | 1 692.04 | |

**Storage pests.** The bruchids *Callosobruchus chinensis*, *C. maculatus*, and *C. theobromae* have all been identified in field-collected samples of pigeonpea. Pod samples collected in surveys have been incubated in the laboratory for emergence studies. In one severe instance, 28 percent of the pods collected had been attacked by bruchids, and up to 5 percent was relatively common. Laboratory studies show that there can be 11 generations of bruchids during a 10-month period at room temperatures.

Preliminary trials using vegetable oil at the rates of 300, 600, and 900 ppm (300 ppm is roughly the equivalent of a half teaspoon of oil to 5 kg of peas) were completed. The peas are coated with oil and exposed to a known number of bruchids. In comparison with untreated peas, far fewer bruchids developed on the seeds coated with oil. This work at ICRISAT is based on that being carried out on cowpeas in Nigeria.

### Looking Ahead in Pigeonpea Entomology

During the next 12 months, there will be a continuation of the work on the biology of the important pest species, with an intensification of work on their alternative hosts, especially out of season. This will be combined with a literature scan for pests of pigeonpea in other areas of the SAT.

Further data will be obtained on actual and potential pest losses, both locally and within the subcontinent of India. At the same time, an intensified search for cultivars of pigeonpea likely to have qualities of use in conferring pest tolerance will be initiated, using screening techniques already developed.

Follow-up work on the use of vegetable oil for protecting pigeonpea during storage and assessment of preharvest levels of bruchid attack and subsequent population build-up during storage will be done. This work will be combined with observations on differential attack on seed of different cultivars of pigeonpea.

## Pathology

A major advance during the year was the standardization of two laboratory screening techniques. The "water-culture" technique consists of using a pure culture of pathogenic *F. oxysporum* multiplied in flasks containing potato-dextrose broth on a shaker for 7 to 10 days. The pure culture is diluted with sterile distilled water to form an inoculum concentration of 2.5 percent. Twenty ml of inoculum is transferred to a glass tube, into which a single 10-day-old pigeonpea seedling (started in sterilized sand) is inserted. Typical symptoms develop in susceptible plants within a week. In the 'sand-culture' technique, the inoculum is multiplied for 16 days on a sand-maize meal medium and then incorporated into sterilized sand at a ratio of 1 to 3. The roots of 7- to 10-day-old pigeonpea seedlings are momentarily dipped into concentrated *F. oxysporum* culture on potato-dextrose broth; the seedlings are then transplanted to pots containing inoculated sand. Symptoms in susceptible plants will develop within 7 days.

Isolations made from wilt-affected plants collected at ICRISAT Center and from several other locations in India yielded varied cultural types. These have been classified into 19 distinct isolates (A through S), all of which are pathogenic.The group "Q" appears to be more widely prevalent than others.

### Sterility Mosaic

A simple and highly effective technique—"leaf-stapling"—was developed and standardized to screen pigeonpea germplasm and breeding material. The technique (Fig 21) brings the mite vector, *Aceria cajani* Channabasavanna, into close proximity to test seedlings. Leaflets from diseased plants carrying the vector are collected and stapled with an office-type stapler to primary leaves of 10- to 15-day-old healthy test seedlings (one or two diseased leaflets per healthy primary leaf). As the diseased leaves dry, the mites move on to the healthy seedlings and transmit the virus.

*Figure 21. Pigeonpea leaf infected with sterility mosaic and infested with the vector* **Aceria cajani**, *then stapled to the primary leaf of a healthy seedling.*

Typical mosaic symptoms usually develop in susceptible seedlings within 10 days.

Preliminary experiments reveal that partial sterility may be due to late infections in the ield. More-natural spread of the disease was bserved during May through July at CRISAT Center.

### reening for Resistance

he "water-culture" technique for wilt and e "leaf-stapling" technique for sterility osaic were employed to begin the screening pigeonpea germplasm. Not one of the more an 300 lines screened so far shows consistent sistance to wilt. Individual seedlings (to date, ) found to survive for 3 days longer than the sceptible check cultivars (Sharda and T-21) re transplanted to inoculated soil in large ts. Attempts are being made, in case they survive, to obtain seeds for further testing under laboratory and field conditions.

Further steps were taken to develop two uniform "wilt-sick" plots of 1.5 hectares each by growing a susceptible cultivar, allowing stubble to become colonized following harvest, and adding more inoculum.

In sterility-mosaic screening, repeated pot and field inoculations have confirmed the immunity of the lines ICRISAT -3783, -6986, 6997, -7035, and cv Hy-3C. So far, about 3000 germplasm accessions, intergeneric crosses, and species of *Atylosia* have been screened. Resistance was not observed in *A. lineata* and *A. platycarpa*.

### Surveys

Systematic roving surveys to study the prevalence of different pigeonpea diseases in Andhra Pradesh and in Maharashtra were carried out as the first stage of the survey program. The average wilt-incidence in Maharashtra was 27.9 percent; in Andhra Pradesh it was 5.26 percent. The incidence of other diseases was low; the more commonly observed diseases, relatively speaking, were sterility mosaic, powdery mildew, and different kinds of leaf-spots.

Survey efforts will be extended to other countries in the near future.

### Seed Pathology

During the year, facilities for following internationally recognized procedures for testing for seed pathogens were established. Preliminary studies were made on the microflora associated with pigeonpea raised at ICRISAT Center; fungi isolated from these included species of *Alternaria, Curvularia, Drechslera, Fusarium, Phoma,* and *Rhizoctonia*. The work will intensify in the coming year, and the cooperative activity with Denmark's Institute of Seed Pathology for Developing Countries will continue.

### Looking Ahead in Pigeonpea Pathology

Techniques for rapid laboratory and field screening for wilt resistance will be refined as needed, and increased emphasis will be put on incorporating resistance in breeding material. Surveys will be continued to determine the distribution and severity of diseases. Cooperative work will be expanded as resistant material is developed, and international multiple-location disease nurseries will be organized.

## Nutritional Quality

Quality evaluations (bioassay and methionine and cystine) were made at the University of Florida and (total sulfur) at IITA on parents in the crossing program. Little variation was found, and there was no correlation (r = -0.24) between the two sets of determinations. Five high-protein lines of intergeneric (*Cajanus* × *Atylosia*) material were analyzed for amino-acid composition, and two were slightly higher than the check in sulfur amino acids (2.24 and 2.29 vs 2.04 for T-21, expressed as g/100 g protein). Encouraging results with total protein have been obtained in selections, $F_2$'s, and intergeneric material. A comparison of the three sources with the germplasm collection is presented in Table III.

This comparison shows that protein percentages near the upper limit of germplasm sources can be readily recovered in conventional breeding programs. Results with the intergeneric crosses show that two of the three *Atylosia* species contribute levels of protein above existing germplasm lines. The highest lines will be intercrossed to provide selection material for higher protein levels.

Preliminary studies of a number of chemical constituents were made during the year (Table 37).

### Looking Ahead in Pigeonpea Nutritional Quality

Rapid accurate testing, along with genetic variability, is essential for improving any quality factor. These conditions exist for total protein, and breeding for this trait will be emphasized. Further development is needed in testing tech-

**Table III**

| Material | No. | Protein %(DBC) | |
|---|---|---|---|
| | | Mean | Range |
| Germplasm lines | 2 172 | 24.4 | 13.5 -27.6 |
| Selections: | | | |
| 891 | 3 | 25.84 | 24.63-26.36 |
| 914 | 3 | 25.80 | 25.19-26.36 |
| 1350 | 4 | 25.54 | 22.91-27.57 |
| 2023 | 3 | 25.61 | 24.63-26.88 |
| Intergeneric hybrid $F_5$ lines: | | | |
| *Cajanus* × *A. lineata* | 99 | 23.54 | 18.77-27.57 |
| *Cajanus* × *A. scarabaeoides* | 55 | 24.88 | 21.53-30.42 |
| *Cajanus* × *A. sericea* | 80 | 25.99 | 23.26-30.15 |
| $F_2$ populations: | | | |
| ICRISAT 4726 × 1 | 100 | 22.4 | 19.1 -26.2 |

niques for sulfur amino acids, and research will continue in this area. Efforts will be made to develop or adopt a rapid method of dehulling small samples and a rapid method of screening for cooking time. Analysis for protein fractions will be carried out on representative cultivars.

## Microbiology

Work on microbiology of the pigeonpea began in 1976. Nodulation on plants sown on black soil during rainy season 1975 at ICRISAT Center seemed adequate. On plants sown dur-

**Table 37. Results of laboratory measurements conducted on pigeonpea seed, 1975-1976.**

| | |
|---|---|
| Range in protein in dhal (n=2 262) | 18.4–28.8% |
| Correlation between microKjeldahl method and DBC method (protein, n=470) | 0.936 |
| Oil in whole grain (n=40) | 0.9–1.8% |
| Oil in dhal (n=24) | 1.7–2.7% |
| Seed-coat percentage (n=24) (based on actual seed-coat wt obtained) | 11.0–20.0% |
| Seed-coat protein (n=24) | 3.5–7.3% |
| Ether extract in seed-coat (from pooled seed-coat from 67 lines) | 0.46% |
| Correlation between seed-coat and 100-grain weight (n=67) | –0.71** |
| Starch (anthrone method, n=24) | 47.6–58.6% |
| Soluble sugars (anthrone) | 2.4–6.3% |
| Moisture | 10.2–11.5% |
| Nonprotein nitrogen (n=1) | 18.2% |
| Albumin + globulin | 46% |
| Cystine (GOA method - colorimetric, n=14) | 1.14–1.60% of p |
| Methionine (Microbiological, n=6) | 1.09–1.12% of p (0.21 - 0.31% sample) |

ing the post-rainy season on red and on black soil, nodulation was sparse and generally ineffective, presumably a response to the cooler soil temperatures.

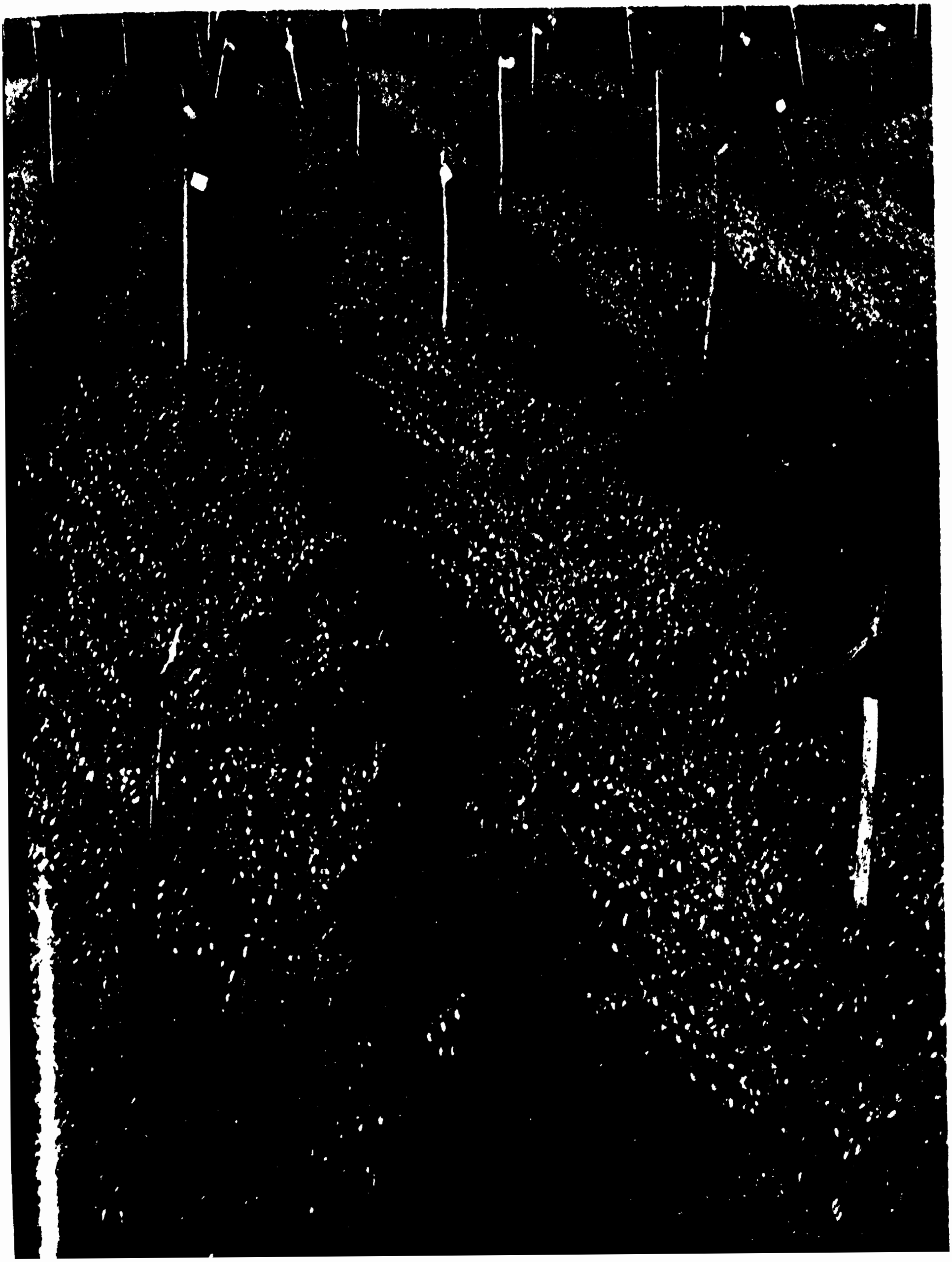
### Looking Ahead in Pigeonpea Microbiology

The numbers of *Rhizobia* nodulating chickpea and pigeonpea and their effectiveness in nitrogen fixation will be determined for selected sites, in order to follow the effects of soil type, season, and cropping pattern on *Rhizobium* populations. This will help in predicting the response to inoculation with *Rhizobium*. The effect of seed inoculation with highly effective *Rhizobia* strains will be examined in field experiments, looking at the proportion of nodules formed by the inoculum strain, the persistence of the inoculum in soil, as well as effects on nitrogen fixation and yield. Even if inoculation produces only a 10-percent increase in yield, it will be an economic practice for farmers to adopt. Methods of producing inoculants and inoculating seed to ensure successful nodulation will be sought.

Breeders' elite crossing material will be examined to see if there are lines which are superior in nodulations and nitrogen fixation. The heritability of these characters will then be determined so that ways of increasing nitrogen fixation by these crops can be explored.

**ERRATUM.** In the 1973/74 *Annual Report* of ICRISAT, it was stated that natural crossing of up to 65 percent had been found in pigeonpea. This statement was based on a secondary reference to the work of Howard, Howard, and Khan as reported in 1919 in the Imperial Department of Agriculture in India's *Botanical Series* Vol X, No 5, pages 202-203. In perusing the original work, which reached us only recently, it was noted that in one case 65 percent of the progenies observed contained hybrid plants; the frequency of hybrids based on flower color was 2.25 percent of the total plants observed. We have since been quoted by others; we regret our role in perpetuating another author's error.

# CHICKPEA



# Chickpea

Approximately 10.5 million hectares of chickpea were grown in the world during 1972, a 3.5-percent increase since 1952. Total production increased in the major chickpea-growing countries—India, Pakistan, Ethiopia, Mexico, Turkey, Iran, Burma and Morocco—but decreased in Italy and Spain. During the same period there has been a phenomenal increase in human population, and chickpea is thus in short supply in the major consuming countries. India, for instance, has banned the export of chickpea.

Two types of chickpea are grown: "desi" (12 to 18 g per 100-seed weight, usually with yellow to brown testa) and "kabuli" (20 to 30 g per 100-seed weight, with a salmon white testa). Chickpea can also be grouped according to either "winter" (Oct/Nov, post-rainy season) or "summer" (Mar/Apr, hot dry season) plantings. The winter-planted crop is mostly desi, planted from Pakistan eastward. The summer-planted crop is mostly kabuli, planted from Afghanistan westward into the Middle East, southern Europe, and North Africa. There is an overlap of desi types adapted to summer plantings in Iran and Afghanistan. The Ethiopian and Sudanese crops are mostly winter-planted desi types. Chile, Argentina, and Peru grow kabuli types from September to January; Mexico grows both desi (garbanzo porquero) and kabuli (garbanzo blanco) from October to February. About 80 percent of world production is desi, but kabuli is grown in nore countries. ICRISAT's breeding program ncludes provisions for improving both types. ɿy using divergent selection, the same cross an be utilized for production of both types.

he aims of the breeding program are:

1. To breed high-yielding disease-resistant high-quality cultivars with stability of performance.

2. To contribute advanced breeding lines and segregating populations for strengthening regional and national research programs.

3. To help governments boost chickpea production through the supplying of seed and of technology, and the training of scientific staff.

## Germplasm

### Collection

Chickpea genetic resources now total 10 607 accessions of *Cicer arietinum* L. and 47 accessions of wild *Cicer* spp. Of these, 1 082 were added during the present report year (Tables 38, 39).

During post-rainy season 1974, only 5 836 of the 8 916 lines could be fully observed. In the remaining 3 080 lines, stand was poor or growth was affected due to salt patches in the field, lodging, or other causes. These lines were evaluated again in 1975-1976.

Table 40 gives some of the interesting ranges of variability found in the germplasm.

In post-rainy season 1975 at ICRISAT Center, 5 192 Indian and exotic lines were sown on 13 and 14 November; the seeding was late because of incessant rains. At Hissar (Haryana Agricultural University), 2 724 exotic lines were grown in the expectation of a more proper expression. Sowing took place on 16 and 17 October 1975, the optimum sowing time. However, nonadaptability of the exotic lines seems even more striking at Hissar than at ICRISAT Center. Chickpea stunt (virus?), wilt, and white ants affected the majority of the lines to some extent, as did a hard pan layer widespread in the soil. At ICRISAT Center only scattered cases of wilt and stunt were observed.

Plants were observed for the characters listed in earlier reports (Annual Report, ICRISAT, 1974-1975); in addition, stem color and number of tertiary branches were noted.

The planting method at ICRISAT Center was the same as that employed in the previous year (two 3-m rows on ridges 75 cm apart), while at Hissar flat planting was used (single 5-m rows spaced at 60 cm). The ICRISAT Center plantings were irrigated after sowing and again on 19 January. Pre-sowing irrigation was supplied at Hissar.

Complete evaluation was obtained from 2817 lines at ICRISAT Center and 764 lines at Hissar. Growth was good, but a stand of 50 percent or less was prevalent in 812 lines. From both locations, samples for detailed seed observation and protein analysis became available.

Sample data on 300 lines were processed at the Taximetrics Laboratory of the University of Colorado; these form the initial base for the preparation of the germplasm catalog. All data are now being processed similarly.

Popova's classification (1937) of chickpea "varieties" has been translated into English. After accumulation of all observations, the key can be used. However, descriptor classes need to be adjusted for the ICRISAT Center location and probably for other locations. Classification can be carried out subsequently.

**Table 38. Chickpea germplasm lines at ICRISAT Center, 31 May 1976.**

| Country of Origin | Entries Total | Entries New[a] | Country of Origin | Entries Total | Entries New |
|---|---|---|---|---|---|
| | (no) | (no) | | (no) | (no) |
| India | 4469 | 621 | Cyprus | 20 | |
| Iran | 3858 | 31 | Italy | 18 | |
| Afghanistan | 615 | 307 | Lebanon | 18 | 1 |
| Turkey | 304 | 73 | Algeria | 18 | |
| Mexico | 157 | 3 | Syria | 12 | |
| Ethiopia | 143 | | Burma | 6 | |
| Pakistan | 123 | 37 | Bulgaria | 5 | |
| USA | 90 | | Hungary | 4 | |
| Spain | 79 | | Portugal | 4 | |
| USSR | 73 | | Sudan | 4 | |
| Morocco | 52 | 3 | Sri Lanka | 3 | |
| Egypt | 50 | 1 | Nigeria | 3 | |
| Israel | 48 | 1 | Yugoslavia | 2 | |
| Via Netherlands | 46 | | France | 1 | |
| Tunisia | 30 | | Peru | 2 | |
| Greece | 24 | | Colombia | 1 | 1 |
| Jordan | 23 | | Unknown | 282 | 3 |
| Iraq | 20 | | | | |
| | | | Total | 10607 | 1082 |

[a] Added in 1975-1976

**Table 39. Annual and perennial wild relatives of the chickpea at ICRISAT Center.**

| Species | Origin | Collector(s) | Samples |
|---|---|---|---|
| Annual | | | |
| *Cicer bijugum* K.H. Rech. | Turkey, Diyarbakir | van der Maesen Ladizinsky | 5 |
| *C. chorassanicum* (Bge) M. Pop. | Afghanistan, Bamiyan | van der Maesen G.C. Hawtin | 3 |
| *C. cuneatum* Hochst. ex. Rich. | Ethiopia, Axum | Seegeler | 1 |
| *C. echinospermum* P.H. Davis | Turkey, Siverek | van der Maesen, Ladizinsky | 3 |
| *C. Judaicum*, Boiss. | Israel, Lebanon | Ladizinsky, Hawtin | 4 |
| *C. pinnatifidum* Jaub. & Spach | Turkey, Harput | Ladizinsky, van der Maesen | 7 |
| *C. reticulatum* Ladizinsky | Turkey, Savur | Ladizinsky, van der Maesen | 4 |
| *C. yamashitae* Kitam | Afghanistan, Sarobi | van der Maesen G.C. Hawtin | 3 |
| Perennial | | | |
| *C. anatolicum* Alef. | Turkey, C & E | van der Maesen | 3 |
| *C. floribundum* Fenzl. | Turkey, Yarpuz | " | 1 |
| *C. microphyllum* Benth. | India, Lahaul | " | 1 |
| *C. montbretii* Jaub. & Spach | Turkey, Bergama | " | 2 |
| *C. pungens* Boiss | Afghanistan, Central | van der Maesen, G.C. Hawtin | 9 |
| *C. rechingeri* Podlech | Afghanistan, Panjao | van der Maesen, G.C. Hawtin | 1 |
| | | | 47 |

Table 40. **Variability observed in chickpea and wild annual *Cicer* spp. at ICRISAT Center plantings.**

| | Chickpea *Cicer arietinum* (1974-1975) | Wild Annual *Cicer* species (1975-1976) |
|---|---|---|
| 1. Time to 50% flowering (days) | 39-94 | 72-104 |
| 2. Plant height (cm) | 22.0 - 90.3 | |
| 3. Plant width (cm) | 19.0 - 124.0 | |
| 4. Pods per plant | few to 228 | |
| 5. Seeds per pod | 1.0 - 3.02 | 1.0 - 2.09 |
| 6. Time to maturity (days) | 92-137 | 109-164 |
| 7. 100-seed weight (g) | 4.29 - 60.6 | 1.36 - 18.6 |
| 8. Protein content (%) | 14.50 - 24.45 | |

Quite a few materials described by Popova are not present in our collection; this invites new attention to his early screening at Tashkent in the 1930's.

**Collection trips.** ICRISAT's germplasm botanist traveled to Turkey and Afghanistan, collecting eight species of *Cicer* (total of 29 samples) in Turkey and four (total of 21 samples) in Afghanistan. Other wild and cultivated *Leguminosae* and other families were gathered. In most cases (108 and 136 samples), voucher herbarium has been prepared. The collection trip to West Bengal (Annual Report, ICRISAT, 1974-1975), overlaps the periods reported here.

In March and April 1976, northwest Karnataka, Rajasthan, and adjoining Haryana were searched; 215 chickpea samples were obtained from these areas, which hitherto were scarcely represented.

Tours to observe chickpea crops and research plantings in Lahaul valley (Oct 1975); Raichur and Gulbarga (Dec 1975); Bangalore and Coimbatore (Jan 1976); Akola, Badnapur, and Rahuri (Jan 1976); and Jaipur, Hanumangarh, Ganganagar, and Hissar (Feb 1976) were made.

**Seed Distribution**

Table 41 lists the destinations of chickpea samples distributed from ICRISAT Center by the germplasm section in 1975-1976. Elite germplasm for multilocation trials was sent out by the breeding section.

**Looking Ahead in Chickpea Germplasm**

Plans are underway for collecting expeditions to northern India for wild *Cicer* species. An August-September expedition to Afghanistan (in collaboration with the ALAD Team) for cultivated and wild *Cicer* will hopefully survey areas which could not be visited in 1975. Additional areas in India, as well as in Bangladesh and Pakistan, will be searched. For the more remote future, off-road locations in Ethiopia may yield useful additions. Turkey, Iran, the Middle East, Greece, and Morocco have material yet uncollected.

Cold-storage facilities acceptable (4°C, low relative humidity) for storing the genetic resources will be installed at ICRISAT Center during the coming year.

The first germplasm catalog, based on 2 years' evaluation of data, is scheduled for publication during the 1976-1977 year.

Table 41. Chickpea seeds distributed from ICRISAT Center by the germplasm section, 1975-1976.

| Samples (no) | Institute | Nation |
|---|---|---|
| 2 | Hunting Technical Services, Khartoum | Sudan |
| 2 | Senior Agricultural Officer | Thailand |
| 103 | Agricultural Research Station, Wagga Wagga | Australia |
| 20 | Bangladesh Agricultural University, Mymensingh | Bangladesh |
| 12 | Agricultural Research Institute, Patna | India |
| 34 | G.B. Pant University of Agriculture and Technology, Pantnagar | India |
| 13 | Mahatma Phule Krishi Vidyapeeth, Rahuri | India |
| 83 | Agricultural Research Station, Badnapur | India |
| 100 | Indian Agricultural Research Institute, New Delhi | India |
| 277 | Economic Botanist II, Berhampore | India |
| 153 | Agricultural Research Station, Raichur | India |
| 6010 | Agricultural Research Organization, Bet-Dagan | Israel |
| 1 | US AID Program | Pakistan |
| 117 | Central Soil and Water Conservation Research and Training Institute, Dehra Dun | India |
| 33 | Haryana Agricultural University, Hissar | India |
| 30 | Station de Genetique et d'Amelioration des plantes, Versailles | France |
| 50 | Department of Botany, University of Birmingham | England |

# Applied Breeding

## Cultivar Improvement

The chickpea-breeding program at ICRISAT was initiated in 1973. In the 1975-1976 season, we were growing $F_4$ progeny rows made possible by growing an off-season (for India) crop in Lebanon and in the Lahaul valley of Himachal Pradesh in northern India.

More than 5000 crosses, including the 2617 made during 1975-1976, have been made since the program began. The ICRISAT crossing block nursery is dynamic in that each year new entries are included and others discarded. Due emphasis is given to multiple crosses, including 3-way, 4-way, and composite crosses. Segregating populations were grown during the regular (post-rainy) season in 1975 at ICRISAT Center near Hyderabad in southern India and at Hissar in Haryana in northern India. These sites differ in agro-climatic conditions, soil type, and length of growing season for chickpea. Selection is carried out for long-term cultivars at Hissar and short-term cultivars at ICRISAT Center; this work should benefit the bulk of the chickpea-growing areas of eastern Asia. We may be able to identify widely adapted genotypes by the use of these two environments.

**$F_1$ generation.** Nearly 2000 $F_1$'s were grown in the Lebanon, the Lahaul valley, and at ICRISAT Center. Multiple crosses were subjected to stringent selection; and two-thirds were rejected. Rejection among single crosses was limited to disease susceptibility.

**$F_2$ populations.** Five-hundred plants of each of 479 and 307 $F_2$ populations of single crosses were grown at ICRISAT Center and at Hissar, respectively. Of these, 255 were desi × desi, 195 desi × kabuli, and 29 kabuli × kabuli combinations. The populations were evaluated as "Very Promising," "Promising," and "Discard." The intensity of selection between crosses is reflected in the few ratings of "Very Promising"—only 2 percent of populations at ICRISAT Center and 3 percent at Hissar, respectively. More than 80 percent of each trial was rated "Discard." Individual plant selections—within selected crosses rated as "Very Promising" and "Promising"—were made, depending upon cross performance and the specific nature of the cross.

Fifteen-hundred plants of each of the 411 $F_2$'s of multiple crosses were grown at ICRISAT Center and at Hissar. These were rated 7 and 12 percent "Very Promising," 18 and 22 percent "Promising," and 75 and 66 percent "Discard" at ICRISAT Center and Hissar, respectively.

Bulk samples from 55 "Very Promising" crosses were taken as $F_3$ populations for distribution to chickpea breeders in other parts of the world.

**$F_3$ progeny rows.** A total of 224 progeny rows (2 rows of 4 m each) were planted at ICRISAT Center and at Hissar under high (60 kg $P_2O_5$/ha) and low (30 kg $P_2O_5$/ha) applications of fertilizer, making four environments. The peas were categorized on visual ratings and yield. One of the progenies (cv ICRI 7469-6-B) of the cross BGI × (H 355 × L 550) gave the highest yield produced (2670 kg/ha) at Hissar, an increase of 30 percent over G 130, the best cultivar of northern India. The parents of this cross were BGI and H 355 (Indian desi cultivars) and L 550 (an Indian cultivar selected from a kabuli × desi cross in northern India).

**$F_4$ progeny rows.** Yields of the top five $F_4$ progenies from ICRISAT Center and from Hissar and the overall best performers at both locations and both high- and low-fertility environments are presented in Table 42. Some progenies yielded 68 and 60 percent higher than the southern Indian (JG-62) and northern Indian (G-130) standard cultivars, respectively. These results are encouraging, considering that they came from crosses made in 1973 when germplasm was limited. Local adaptation appears to be important, and the selection of sites for testing in northern and in southern India appears to have been justified.

A total of 3159 plants were selected for raising $F_5$ progeny rows in 1976. Some $F_4$ progeny lines were earmarked for supply to cooperators in other countries next season.

### Off-season Nurseries

For advancement of breeding material, "off-season" generations were raised in Lebanon and in the Lahaul valley in northern India.

**Lebanon 1975.** This site is a natural environment for growing summer-planted kabuli chickpeas. The $F_2$ populations of crosses grown here proved highly informative in relation to kabuli and desi divergencies and cross performances.

The Indian desi cultivars were mostly susceptible to iron chlorosis in early growth and it was noted that the kabuli × desi crosses were segregating for susceptibility and resistance. There is apparently little shortage of available iron in most soils of eastern Asia otherwise suitable for growing chickpea (natural selection for iron-chlorosis resistance would not have taken place among the desi types). In western Asia and North Africa there is apparently a shortage of available iron in many of these calcareous soils and iron-efficient cultivars are obviously needed for these areas. The deficiency symptoms were corrected at an early stage by application of ferrous sulphate.

At plant maturity (selection time), it was apparent that $F_2$ segregating populations of crosses involving Indian desi × Indian desi

Table 42. **Yield (kg/ha) of the five top yielding $F_4$ progenies during 1975-1976.**

| ICRI No. | Pedigree | ICRISAT Center HF | ICRISAT Center LF | ICRISAT Center Average | Hissar HF | Hissar LF | Hissar Average | % increase over |
|---|---|---|---|---|---|---|---|---|
| | | (kg/ha) | | | | | | cv JG-62 |
| 7389-18-5 | 850-3/27 × F-378 | 3 210 | 3 128 | 3 169 | | | | 68 |
| 73114-15-3 | 850-3/27 × GW-5/7 | 3 977 | 2 243 | 3 110 | | | | 65 |
| 731-8-3 | H-208 × F-61 | 2 533 | 3 663 | 3 098 | | | | 64 |
| 73143-5-1 | JG-62 × Annegiri | 2 777 | 3 333 | 3 055 | | | | 62 |
| 7389-15-1 | 850-3/27 × F-378 | 2 777 | 3 030 | 2 903 | | | | 54 |
| | | | | | (kg/ha) | | | cv G-130 |
| 7330-10-4 | H-208 × EC-12409 | | | | 2 937 | 5 552 | 4 244 | 60 |
| 73126-6-2 | 850-3/27 × E-100 | | | | 4 104 | 3 292 | 3 698 | 39 |
| 73111-8-2 | 850-3/27 × H-208 | | | | 3 229 | 3 854 | 3 582 | 35 |
| 73179-14-1 | G-130 × P-5409 | | | | 3 875 | 3 083 | 3 479 | 31 |
| 73307-10-2 | K-468 × F-378 | | | | 3 687 | 2 958 | 3 323 | 25 |
| | | OVERALL (kg/ha) | | | (kg/ha) | | | JG-62/G-130 |
| 7330-10-4 | H-208 × EC-12409 | 1 608 | 2 595 | | 2 937 | 5 552 | 3 173 | 63 |
| 73126-6-2 | 850-3/27 × E-100 | 2 342 | 2 008 | | 4 104 | 3 292 | 2 936 | 51 |
| 73111-8-2 | 850-3/27 × H-208 | 1 621 | 2 010 | | 3 229 | 3 854 | 2 678 | 38 |
| 73167-5-3 | JG-62 × F-496 | 2 266 | 1 888 | | 3 875 | 2 375 | 2 601 | 34 |
| 7328-8-3 | H-208 × CP-66 | 1 843 | 2 067 | | 2 969 | 3 093 | 2 493 | 28 |
| | JG-62 | 1 927 | 1 841 | | 2 046 | 1 184 | 1 750 | |
| | G-130 | 1 130 | 1 328 | | 3 140 | 2 172 | 1 943 | |

HF = high fertility (60 kg $P_2O_5$/ha added)

LF = low fertility (no fertilizer added)

JG-62 is a standard cultivar in southern India

G-130 is a standard cultivar in northern India

rentage were showing little phenotypic iability, and that it would not be expedient select individual plants from within them. e plants were of short stature and low in ld. A modified bulk method of selection was refore practiced on these crosses. wever, within $F_2$ populations of kabuli × desi crosses, and to a lesser extent within Indian desi × Iranian desi crosses, large phenotypic differences existed between plants and individual plant selection could be carried out with impunity.

From these observations (made on 178 single crosses and 92 multiple crosses), it appears that adaptability is important in chickpea and that the kabuli types are more adapted to western Asia and the desi types (with the exception of the Iranian desis) to eastern Asia. Conceptually, this would be the case if long-time separation of these major types had occurred. If this were true, then it would be more likely, *for instance*, that a superior cultivar for eastern Asia would be produced by a (kabuli × desi) × desi backcross and for western Asia by a (kabuli × desi) × kabuli backcross. This was exemplified in a spectacular fashion in Lebanon by two reciprocal backcrosses involving the cultivars F378 (an Indian desi) and Rabat (a Moroccan kabuli). The two populations, about 800 spaced plants of each, were grown contiguously.

The $F_2$ of (F378 × Rabat) × Rabat was producing widely divergent segregants and it was easy to select the best phenotypes. The $F_2$ of (F378 × Rabat) × F378 "showed" no remarkable divergencies of plant type in the Lebanese environment. All plants within these two backcrosses were harvested and seed weights of individual plants recorded (Table 43).

From within each backcross, we selected 15 high-yielding, 15 low-yielding, and 15 random sample $F_2$ plants and grew them as progeny rows at ICRISAT Center during post-rainy season 1975 (Tables 44, 45). The backcross to cv F378 has produced a higher mean-yield than did the backcross to Rabat, and the possibilities of selecting higher-yielding plants are greater in the former cross in India. This is as predicted. It would appear in both crosses (Table 45) that there may be an inverse relationship between segregant yield in the Lebanon trial and the India trial. Selection for one environment in another would therefore be inappropriate, and only limited advancement of unadapted early generation material is advisable.

It should be noted that, in Lebanon, Indian desi cultivars and segregants—while being morphologically dwarfed—do produce normal mature seeds.

**Lahaul Valley.** This site was chosen as a possible site for off-season advancement in India because of its altitude (elev 10 350 ft) and the fact that there is little "summer" rainfall. It is not an area where chickpea is normally grown.

The 1975 season (May to Sep) was a poor one for chickpea in the Lahaul valley. The season was rainy, cool, and unfavorable for

**Table 43. Production of divergent segregants by backcrosses of F378 and Rabat strains of chickpea ($F_2$ generation, Lebanon 1975).**

| Cross/Parent | % frequency: weight classes | | | | Mean seed weight/plant |
|---|---|---|---|---|---|
| | 0-40 g | 40-80 g | 80-120 g | 120-140 g | |
| | (%) | (%) | (%) | (%) | (g) |
| (F378 × Rabat) × Rabat | 43.4 | 46.6 | 9.7 | 0.3 | 46.3 |
| (F378 × Rabat) × F378 | 79.7 | 19.7 | 0.6 | | 32.8 |
| F378 | 90.0 | 10.0 | | | 22.4 |
| Lebanese Local[a] | 85.0 | 15.0 | | | 25.5 |

[a] N.B. Rabat not grown. Lebanese local is a kabuli type.

Table 44. **Production of divergent segregants by backcrosses for F378 and Rabat strains of chickpea ($F_3$ generation. India 1975).**

| Cross | % Frequency: weight classes | | | Mean seed weight/plant |
|---|---|---|---|---|
| | 0-40 g | 40-80 g | 80-100 g | |
| | (%) | (%) | (%) | (g) |
| (F378 × Rabat) × Rabat | 95.9 | 3.6 | | 22.4 |
| (F378 × Rabat) × F378 | 72.7 | 27.0 | 0.3 | 31.7 |

N.B. Results compiled from mean of five-plant sample from each progeny row.

Table 45. **Selected segregants from backcrosses of F378 and Rabat strains of chickpea.**

| Cross | Mean seed weight/plant | | Correlation $F_2/F_3$ |
|---|---|---|---|
| | Lebanon ($F_2$) | India ($F_3$) | |
| | (g) | (g) | |
| (F378 × Rabat) × Rabat | | | |
| High-yielding segregants | 90.7 | 21.7 | + 0.25 |
| Random segregants | 46.4 | 22.2 | + 0.18 |
| Low-yielding segregants | 10.4 | 23.4 | − 0.47[a] |
| Cross mean | 49.8 | 22.4 | − 0.10 |
| (F378 × Rabat) × F378 | | | |
| High-yielding segregants | 73.3 | 30.6 | + 0.37 |
| Random segregants | 33.0 | 32.9 | 0.00 |
| Low-yielding segregants | 3.4 | 31.6 | − 0.52[a] |
| Cross mean | 36.5 | 31.7 | − 0.31 |

[a]Denotes significance at P<.05

crop growth; some plants did not produce mature seed. Seed produced was only about 40 percent viable. The season also favored the appearance of *Ascochyta* blight in epiphytotic conditions; this destroyed some valuable material, but was useful in identifying lines resistant to the disease.

Seedings were mainly $F_2$'s of single crosses from which new crosses were made. Even though 650 new crosses were made, success in producing $F_2$ seed was only partial.

The disadvantages of this site are many; it is not a natural environment for the chickpea.

### Disease-resistance Breeding

Disease resistance is a major factor in the maintenance of high yield and stability of performance, and some preliminary work on resistance breeding was initiated during the year. Five cultivars with reported resistance to *Fusarium oxysporum f.* sp. *Cicer* and 18 with resistance to *Ascochyta* blight were available for crossing. The cultivar P 9800 (kabuli ex-Afghanistan) was found to be wilt-resistant. Seven cultivars—P 619-1, P 623, P 690, P 6099, P 6308, Chafa, and Pant 104 (all desi's ex-India)—were identified as having moderate blight resistance. In this season, we grew 13 $F_1$'s of wilt-resistant crosses and 37 $F_1$'s of blight-resistant crosses.

Material for wilt resistance will be screened in a wilt-sick plot and for blight resistance through an "isolation plant propagator."

### Fertilizer Response

Chickpea in general does not appear to respond to phosphate application. This may be related to the possibility that the most-effective (for water absorption) roots are very deep for most of the growing season and that applied phosphates remain largely in the surface soil.

During post-rainy season 1974, 498 cultivars were tested for response to 70 kg $P_2O_5$ per hectare—24 cultivars showed a significant negative response. The trial was repeated during post-rainy season 1975 with 10 positive and 10 negative responders (Table 46). All but one cultivar of the "positive" responders gave a

**Table 46. Cultivar response to high fertilizer (70 kg $P_2O_5$/ha) application.**

| Cultivar | 1974-1975 High fertilizer | 1974-1975 No fertilizer | 1974-1975 Difference | 1975-1976 High fertilizer | 1975-1976 No fertilizer | 1975-1976 Difference | Average High fertilizer | Average No fertilizer | Average Difference |
|---|---|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | (kg/ha) | | | (kg/ha) | | |
| P 36 | 2 597 | 1 561 | + 1 036 | 1 396 | 1 253 | + 143 | 1 996 | 1 407 | + 589 |
| NP 34 | 2 203 | 1 536 | + 667 | 1 500 | 1 167 | + 333 | 1 851 | 1 351 | + 500 |
| JG 71 | 2 150 | 1 514 | + 636 | 1 878 | 1 434 | + 444 | 2 014 | 1 474 | + 540 |
| P-1363-1 | 2 084 | 1 381 | + 703 | 1 872 | 1 583 | + 289 | 1 978 | 1 482 | + 496 |
| P 1236 | 2 117 | 1 420 | + 697 | 1 611 | 1 337 | + 274 | 1 864 | 1 378 | + 486 |
| P 3951 | 1 445 | 1 970 | − 525 | 1 340 | 1 628 | − 288 | 1 392 | 1 799 | − 407 |
| T 18 | 1 625 | 2 231 | − 606 | 1 556 | 1 729 | − 173 | 1 590 | 1 980 | − 390 |
| P 150 | 2 039 | 2 564 | − 524 | 1 642 | 1 781 | − 139 | 1 840 | 2 172 | − 332 |
| P 234 | 1 420 | 2 022 | − 602 | 1 812 | 1 812 | 0 | 1 616 | 1 917 | − 301 |
| P 1 | 1 161 | 1 689 | − 528 | 1 750 | 1 809 | − 59 | 1 455 | 1 749 | − 294 |
| CD 5% = | | | 487 | | | 219 | | | |

positive response in 1975; only one of the "negative" responders gave a significant negative response in the 1975 trial.

Cultivars giving the positive response in post-rainy season 1975 were used in our crossing program.

### Protein Content

The development of high-yielding cultivars with stability of performance is a main objective at ICRISAT. As and when those goals are achieved, we shall incorporate high protein content into high-yielding strains. Meanwhile, ICRISAT biochemists and nutritionists are collecting basic information about quality of cultivars. An analysis of protein percentage in desi cultivars showed a range from 14.5 to 25.2 percent (18.5%), and in kabuli cultivars from 13.9 to 26.2 percent (mean 18.2%).

The protein content of large-seeded cultivars (exceeding 25 g/100 seeds) and small-seeded cultivars (weighing less than 15 g/100 seeds) was 18.4 and 18.2 percent, respectively.

### Recurrent Selection

The ICRISAT program to date has utilized the classical methods of breeding—pedigree, bulk, and so forth. However, ICRISAT breeders are also investigating Jensen's diallel selective-mating system as a means of creating "diverse" and "dynamic" gene pools from which to select high-yielding cultivars.

Work has started on three diallels, based on 11 × 11, 20 × 20, and 22 × 22 cultivar combinations. Parents for these diallels were chosen for their morphological variability and their genetic and geographical diversity. As an example, the 22 × 22 diallel contains cultivars varying in different morphological characters and has 13 kabuli and 9 desi types originating from 19 countries.

### International Cooperation

International cooperation during the 1975-1976 ICRISAT year received high priority. The different kinds of nurseries supplied by us to various countries during the 1975-1976 winter season are listed in Table 47.

Results from 10 of the 24 International Chickpea Cooperative Trials have been received and others are coming in. The total results will be compiled and published elsewhere, but Table 48 gives the mean performance of the five top-yielding cultivars. The yields of the highest-yielding cultivars at each location ranged from 812 to 3 854 kg/ha, giving an increase of 231 to 817 kg/ha (13 to 378%) over the best local varieties. The highest aver-

**Table 47. International chickpea nurseries supplied during the 1975-1976 winter season.**

| Country | Sets of Material | | |
|---|---|---|---|
| | ICCT | ECG | $F_3$ Bulks |
| Pakistan | 4 | 2 | 3 |
| Thailand | 2 | 2 | — |
| Chile | 2 | 1 | 1 |
| Ethiopia | 2 | 1 | 1 |
| Sudan | 2 | 1 | 1 |
| Burma | 2 | 1 | — |
| Mexico | 2 | 1 | 1 |
| Bangladesh | 2 | 1 | 1 |
| Philippines | 1 | 2 | — |
| India | 3 | 3 | 3 |
| Yemen | 1 | — | — |
| Nepal | 1 | — | — |
| TOTAL : | 24 | 16 | 11 |

ICCT = International Chickpea Cooperative Trial (49 cultivars, mostly desi types this season)

ECG = Elite Chickpea germplasm (200 cultivars representing a wide range of types)

$F_3$ bulks = Best ICRISAT segregating bulks for plant selection for local adaptation in the countries concerned.

age yield of 2 073 kg/ha was recorded by K-468, a variety developed at Kanpur, India.

Reports received from Ethiopia, Sudan, and India indicate that some of our $F_3$ populations have given excellent segregants, and have been selected for further advancement.

Cooperators were encouraged to visit ICRISAT chickpea plots during the season and select material for themselves. In addition, a list of promising material is published for breeders, ICRISAT will supply material on request, and will try to meet specific requirements of its cooperators. In this spirit, ICRISAT has supplied thousands of genotypes and segregants to a large number of scientists throughout the world, and cooperative efforts between ICRISAT and chickpea-growing countries are expanding.

**Looking Ahead in Chickpea Breeding**

1. A resistance-breeding program in collaboration with ICRISAT pathologists is being launched.

2. The supplying of segregating $F_3$ generation bulks to cooperators will continue; early generation selection in diverse environments is the best means of obtaining good locally adapted cultivars.

Soon, $F_5$ progeny lines and elite chickpea cultivars will be available.

3. The 1975-1976 winter season was the first in which we had an organized international cooperative program in operation; the response from our cooperators was very encouraging. Most of the work was in countries growing desi cultivars in the "winter" season.

During the latter months of 1976, we shall extend similar cooperation to the nations of western Asia, North Africa, and southern Europe which grow Kabuli cultivars as a "summer" crop.

4. In September 1976, trainees from Ethiopia, Sudan, Pakistan, and Bangladesh are expected. We regard training of individuals to do chickpea-improvement work to be a most important task, and welcome opportunities to serve in this way.

I e I

| va | Ethiopia | Ch | | Yemen Arab Republic | | ndia | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Hidango | ı-Plantina | Ausai fera | bb | Pant-nagar | New Delhi | His-sar | Jabal-pur | Hyde-rabad | |
| | | | | | (kg/h | | | | | | |
| K 468 | 2 175 | 561 | 385 | —[a] | 1 588 | 2 783 | 678 | 3 854 | 3 396 | 2 243 | 2 073 |
| BG1 | 1 869 | 812 | 296 | — | 3 562 | 2 667 | 711 | 2 917 | 2 528 | 1 792 | 2 019 |
| C 214 | 2 418 | 662 | 558 | 363 | 1 170 | 2 383 | 886 | 3 667 | 2 868 | 2 681 | 1 866 |
| P 1137 | 2 095 | 491 | 321 | 210 | 1 453 | 2 633 | 126 | 3 104 | 2 965 | 3 090 | 1 849 |
| NEC 240 | 2 018 | 654 | 231 | 756 | 1 252 | 2 767 | | 2 146 | 2 889 | 2 292 | 1 784 |

*Conferences and workshops are held frequently so that scientists may visit the Institute, examine and select breeding material that may prove useful in their own programs, and exchange ideas with each other and with ICRISAT's scientific staff.*

## Physiology

Most of this year's experimental work was carried out on plants grown in the post-rainy season at ICRISAT Center. Some trials were also conducted in the same season at Hissar (Haryana). In the hot dry season of 1975, experiments were conducted on chickpeas grown at an elevation of 10 350 ft in the Lahaul valley (Himachal Pradesh). Average yields at ICRISAT Center (700 to 1 200 kg/ha) were lower than usual, because plantings were delayed by late rains; in Hissar, the yields of [illegible]00 to 5 000 kg/ha were unusually good. In the Lahaul valley, the yields were low (600 to 900 kg/ha) because of atypical and unfavorable weather.

Nitrogen uptake and distribution, yield components, harvest index, the double-podded character, pod position, row orientation, and the effect of seed grading on yield were among the physiological aspects studied.

### Nitrogen Uptake and Distribution

Nitrogen distribution within the shoot system throughout the growing season was studied in five cultivars at ICRISAT Center. In all cultivars, the total amount of nitrogen in the plants reached a maximum soon after flowering began and thereafter declined (data for cv JG-62 are shown in Fig 22). The net loss of nitrogen from the plants was largely due to leaf-fall.

After 50 to 60 days, the percentage of nitrogen in leaves and stems in all cultivars

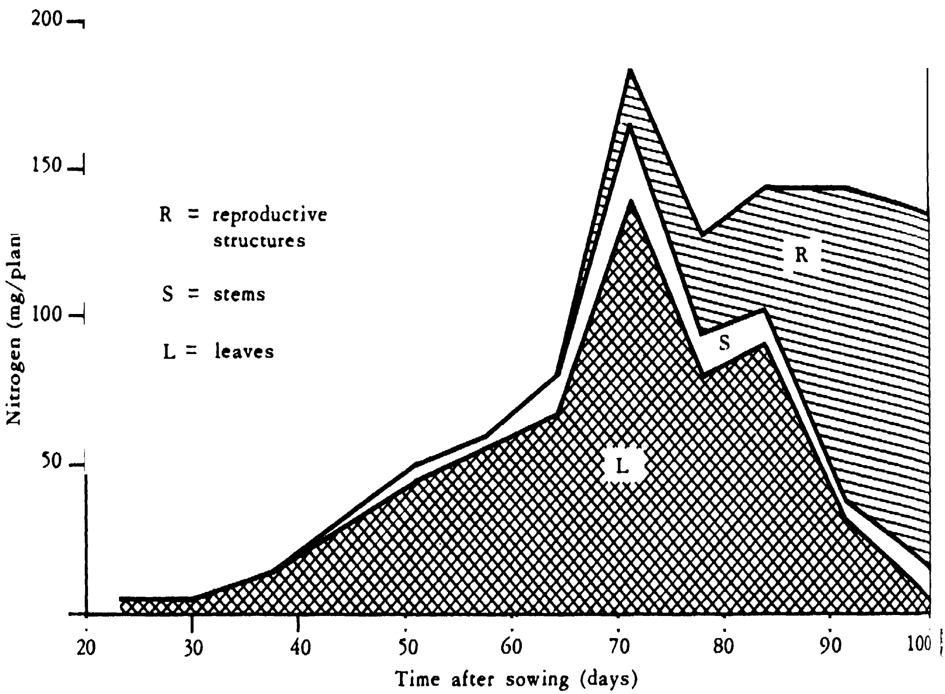



**Figure 22. Absolute nitrogen content in leaves, stems, and reproductive structures of chickpea.**

declined (see Fig 23). The nitrogen remobilized from stem and leaves during the reproductive period accounted for 48 to 96 percent, depending on the cultivar, of the nitrogen in the grain. The decline in nitrogen percentage in pods reflects the fall in nitrogen percentages which occurs during the development of individual pods. The lower percentage of nitrogen in the later-formed flowers, when compared with flowers formed earlier, suggests that these newly developing organs may have been progressively starved of nitrogen towards the end of the reproductive phase.

## Analysis of Yield Components

The indeterminate growth pattern of chickpea means that flowers continue to be produced during the reproductive period at progressively more apical nodes; consequently the earliest-formed pods are found at the most basal pod-bearing nodes, and the latest-formed pods at the most apical.

At the time of harvest, pods were collected nodewise from main shoots, primary branches, and secondary branches; pod numbers, pod weights, seed numbers, and seed weights were recorded. In the six cultivars examined, a similar pattern was found—a progressive decline in number of pods per node, pod weight, seeds per pod, and 100-seed weight in the later-formed more apical pods (Fig 24). In addition, these yield components had lower values on secondary branches than on primary branches and on primary branches than on main shoots. This pattern suggests that the development of the later-formed pods may have been limited by declining supplies of photoassimilates or nitrogen, or of both.

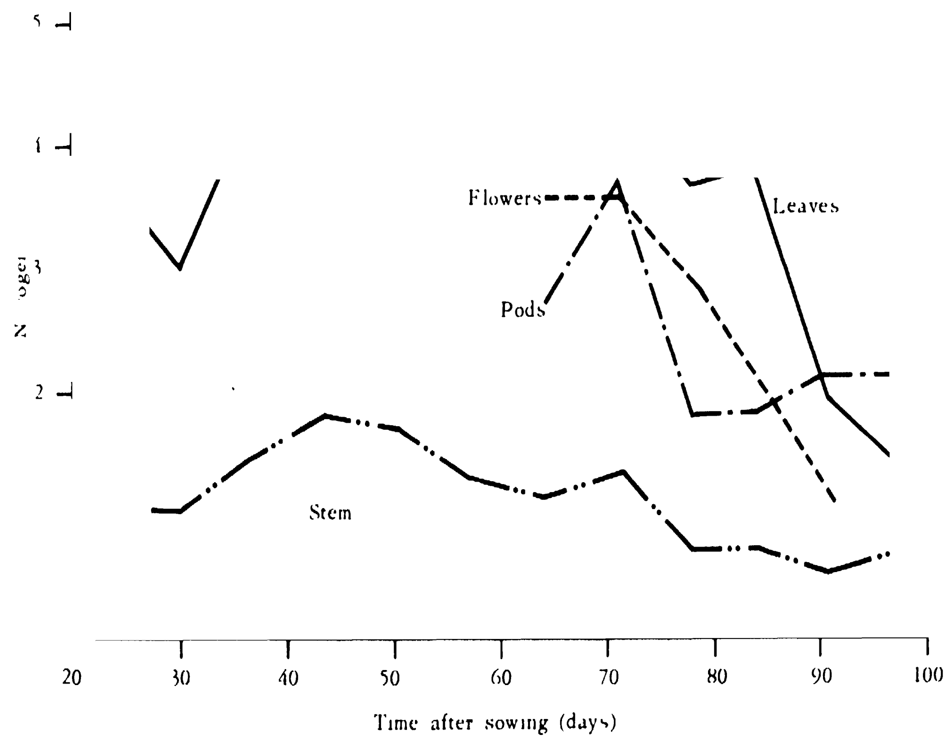



**Figure 23. Nitrogen as percentage of dry weight of flowers, pods, leaves, and stems of chickpea.**

### Harvest Index

The harvest index is defined as the economic yield divided by the total dry matter of the plants at the time of harvest; it is a measure of the partitioning of the total dry matter between reproductive and vegetative structures. The measurement of the harvest index in legumes is complicated by the fact that leaves which fall off before harvest are not usually taken into account and thus the harvest index is overestimated. We investigated the extent of this overestimation with four Kabuli and four desi cultivars of chickpea by collecting periodically all the leaves which fell from a given number of plants. The ground beneath these plants was covered with muslin cloth, and the collecting area bordered with a low "fence" of mosquito netting to prevent fallen leaves from blowing away. Harvest indices taking these fallen leaves into account were calculated; corrected and uncorrected harvest indices are shown in Table 49. On an average, uncorrected harvest indices were overestimated by 31 percent in Kabuli cultivars and by 22 percent in desi cultivars. Ranking was not much affected by the correction, so uncorrected harvest indices may therefore be useful in giving a rough indication of the relative differences between cultivars.

## "Double-podded" Character

Several chickpea cultivars produce two flowers, rather than the usual single flower, per node. They are capable of setting two pods per node and are known as "double-podded" cultivars. However, two pods are formed at only some of the nodes (usually at more-basal older nodes) and the proportion of nodes bearing two pods is strongly influenced by the environment. For example, in cv JG-62 30 percent of the nodes were "double-podded" at ICRISAT Center, 7 percent in the Lahaul valley, and only 2 percent at Hissar.

In order to investigate whether the "double-podded" character is of advantage in terms of yield, four "double-podded" cultivars were converted to "single-podded" plants by cutting off the second flowers formed at each flowering node. Plants in the control plots were untreated. At ICRISAT Center, the removal of the second flower at each flowering node caused a significant decline in the total number of pods produced and a significant reduction in yield (Table 50). The reduction in pod number averaged over all cultivars was 22 percent; reduction in yield (9%) was less because the plants compensated for the reduction in pod number by producing larger seeds and more seeds per pod.

In the Lahaul valley, conversion of "double-podded" to "single-podded" plants had no significant effect on number of pods per unit area or on yield. The percentage of "double-podded" nodes on the control "double-podded" plants was so low (5.5% averaged over the four cultivars) that this result is not surprising.

Taken together, these experiments indicate that the "double-podded" character, under environmental conditions in which the character is well-expressed, may help to give significantly higher yields in some of the cultivars possessing it.

## Position of the Pods

In several leguminous species, photosynthesis in the pod wall has been shown to make an important contribution to the growth of the

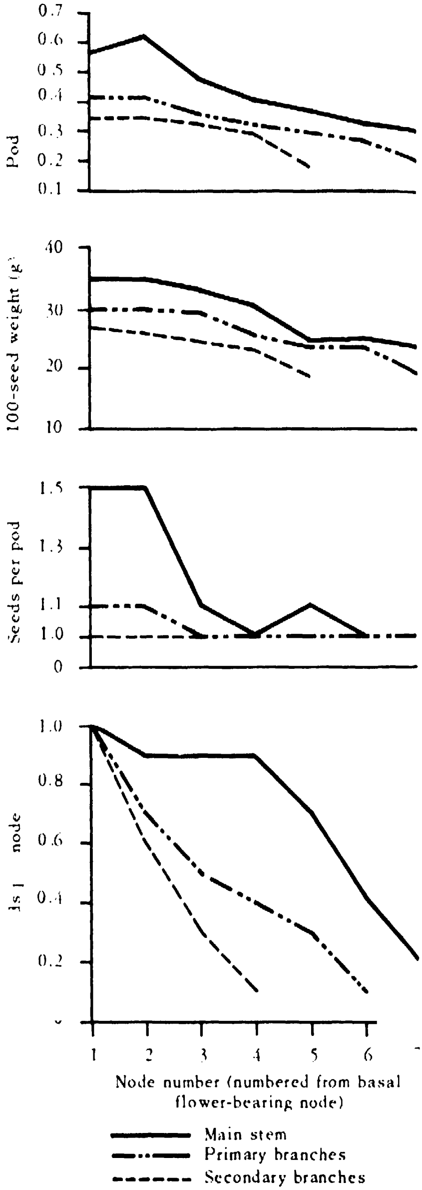



**Figure 24. Components of yield, nodewise, on main stem, primary branches, and secondary branches of chickpea.**

seeds; thus it seems probable that in chickpea the pod wall may be a significant site of photosynthesis.

Chickpea pods are usually subtended below the leaves and consequently shaded. In a few mutant lines however, pods are borne above the leaves. To investigate whether unshaded pods could lead to increased yield through increased pod photosynthesis (or in some other way), pods of four cultivars were shifted above the leaves. Once placed in this position they remained there, and newly formed pods were shifted as they appeared. In the control plots, pods were left in the normal shaded position.

Neither at ICRISAT Center nor in the Lahaul valley did pod position have a significant effect on yield. The "exposed-pod" character therefore seems unlikely to be useful in breeding for higher yield.

**Seed Grading and Yield**

In a given seed-lot of chickpea, there is considerable variation in seed size; the larger seeds produce larger faster-growing seedlings than do the small seeds. The effects of seed grading on final yield were investigated at Hissar, the Lahaul valley, and ICRISAT Center. Large seeds, small seeds, and ungraded seeds of three cultivars were planted at each location. Seed grading produced no significant effect on yield in any cultivar at any location.

**Orientation of Rows**

With several crops, orientation of the rows has been shown to have some influence on light interception and final yield. We compared the effect of north-south and east-west row directions at ICRISAT Center (lat 17°27'N) and at Hissar (lat 29°10'N), using two chickpea cultivars. At neither location was there a significant effect of row direction on yield.

**Looking Ahead in Chickpea Physiology**

The great differences in growth and yield at ICRISAT Center and at Hissar need to be

**Table 49. Effect of leaf fall on HI (harvest index) and its ranking in chickpea cultivars.**

| Type | Cultivar | Harvest Index(HI) Corrected | Harvest Index(HI) Uncorrected | Mean | Increase (Uncorrected/ corrected) | Ranking Corrected | Ranking Uncorrected |
|---|---|---|---|---|---|---|---|
| | | | | | -(%)- | | |
| Kabuli | Leb. Local | 34 | 44 | 39 | 29 | 6 | 5.5 |
| | L-550 | 38 | 50 | 44 | 31 | 4 | 4 |
| | K-16-3 | 34 | 42 | 38 | 23 | 6 | 7 |
| | Rabat | 29 | 41 | 35 | 41 | 8 | 8 |
| | Mean | 34 | 44 | 38 | 31 | | |
| Desi | BEG-482 | 34 | 44 | 39 | 29 | 6 | 5.5 |
| | Chaffa | 53 | 61 | 57 | 15 | 1 | 1 |
| | JG-62 | 46 | 54 | 50 | 17 | 2 | 3 |
| | 850-3/27 | 43 | 55 | 49 | 28 | 3 | |
| | Mean | 44 | 53 | 48 | 22 | | |

D (0.05) : Cultivar means 3.7, treatment means 1.2, treatments within a variety 3.5, varieties within a treatment 4.4.

analyzed further; a number of experiments will be done at both locations to obtain comparative data. Additional studies of the supply of photo-assimilates and nitrogen to the developing pods and of other factors which may be limiting yield will be made. In cooperation with ICRISAT economists, reasons for poor stands of chickpea in farmers' fields will be investigated in village-level studies. Varietal differences in the ability to germinate under limiting moisture supplies will be studied, as will varietal differences in plant plasticity. The former may lead

**Table 50. Yield and number of pods of "double-podded" and "single-podded" plants of four "double-podded" cultivars grown at ICRISAT Center.**

| Cultivars | JG-62 | P-436 | P-272 | P-502 | |
|---|---|---|---|---|---|
| | Yield | | | | Mean |
| TREATMENTS: | (kg/ha) | (kg/ha) | (kg/ha) | (kg/ha) | (kg/ha) |
| Control ("double-podded") | 999 | 1 025 | 1 068 | 1 278 | 1 092 |
| "single-podded" | 889 | 895 | 910 | 1 265 | 990 |
| Mean | 944 | 960 | 989 | 1 271 | |
| NUMBER OF PODS PER UNIT AREA | | | | | |
| | ($no/m^2$) | ($no/m^2$) | ($no/m^2$) | ($no/m^2$) | |
| Control ("double-podded") | 839 | 969 | 858 | 1 072 | 935 |
| "single-podded" | 703 | 662 | 673 | 871 | 727 |
| Mean | 771 | 815 | 765 | 972 | |

LSD (0.05)

| | Cultivars | Treatment | Treatment in a cultivar | Treatment between cultivars | cv% |
|---|---|---|---|---|---|
| For yield | 195 | 44 | 88 | 205 | 5.5 |
| For pods/$m^2$ | 124 | 47 | 93 | 141 | 7.3 |

to cultivars which can better-establish themselves under limiting moisture; the latter to cultivars which can perform well in variable plant stands, such as those frequently encountered in the field.

## Entomology

### Pest Species and Status

1. At ICRISAT Center, 20 insect species feeding on chickpea have been identified; detailed examination of the crop in unsprayed situations is carried out routinely and seasonally.

2. Only 3 of the 20–gram pod borer, *Heliothis armigera* Hub; cutworms, *agrotis* sp; and the lesser army worm, *Spodoptera exigua* –can be considered to be regular pests.

3. *H. armigera* is by far the most important and damaging pest.

4. Evidence is accumulating that *Aphis craccivora* Koch is a disease vector of some importance (see chickpea pathology, page 137) in the crop.

5. The storage bruchids, *Callosobruchus chinensis* and *C. maculatus*, are very damaging in stored chickpea.

### Pest Biology

Data on *H. armigera* is given in the report on pigeonpea (page 102). Some work has been done on storage bruchids.

### Crop- and Storage-loss Studies

Detailed counts during the entire growth cycle were carried out on the chickpea crop at ICRISAT Center. The data were supplemented by surveys in Andhra Pradesh, Maharashtra (Sholapur), and Bihar (Ranchi). In early growth *Agrotis* sp., *S. exigua*, and very young larvae of *H. armigera* acted as foliage feeders. The latter browsed on young apical leaves, fruiting forms, and young pods. The main damage, however, was undoubtedly caused by third-stage and later larvae to the pods. Counts on some cultivars at ICRISAT Center showed that damage could be as high as 37 percent. The mean for all sites in 1974-1975 was 20 percent; on observational plots during 1975-1976, it was 33 percent. Within Andhra Pradesh, the 1974-1975 surveys gave a range of 3.4 to 24.4 percent loss and the 1975-1976 surveys 1 to 20 percent. In Sholapur and in Ranchi, damage was recorded to be 12 and 34.8 percent respectively. A pod damaged by *H. armigera* is almost invariably a total loss.

It is significant that no bruchids were incubated from chickpea pods collected either in the routine surveys or at ICRISAT Center.

**Control.** A small trial was conducted with cv C235 in which half the plot was sprayed regularly with insecticide and additional hand picking was carried out to control pests. Comparison of yield data showed yield losses equivalent to 433 kg/ha. Unsprayed plots yielded only 709 kg/ha.

A trial similar to that reported for pigeonpea (page 110) used vegetable oil to control bruchids in stored chickpea. A range of dosages–600, 900, and 1 200 ppm–was used. Five-hundred seeds were exposed to 10 adult bruchids. In most instances, oviposition was heavy, but the number of eggs laid was definitely less on the 1 200 ppm treatment. The number of adult bruchids emerging from 3 000 seeds on each treatment, after incubation at room temperature for a month, is given in Table I.

**Table I**

| Treatment | Bruchid count (no) |
|---|---|
| Oil (600 ppm) | 155 |
| Oil (900 ppm) | 144 |
| Oil (1 200 ppm) | 49 |
| No Oil | 683 |

**Screening techniques.** As a preliminary to development of methods of screening for insect resistance, 24 chickpea cultivars of diverse plant habit, flower color, and origin were sown in a replicated small plot trial. Detailed pest counts were carried out both in the field and on stored samples of the grain after harvest. An attempt to screen the same cultivars in a screenhouse with released moths failed owing to poor plant growth, staggered flowering, and inability to prevent straying of larvae.

Results indicated that the Mediterranean types (usually white-flowered) were more heavily attacked than the local (desi) types. Damage levels on the former ranged from 14.7 to 32.8 percent (mean 21%), while in the latter it was from 21.1 to 14.3 percent (mean 8%). Plant habit did not appear to affect severity of attack.

The AICPIP grain trials (GCVT's I & II and GIET)[1] were grown as a collaborative venture. Of the 14 cultivars in the GCVT I (irrigated) and GCVT II (unirrigated) trials, cv H 208 was least attacked (6% or less) by pod borers. The most-commonly grown local cultivar, BEG 482, was 7 to 10 percent damaged. In the GCVT I, cv 850 - 3/27 showed 23.8 percent boring; in GCVT II, cv JG 897 was 12.3 percent bored. Pest levels were heavier in irrigated situations. The differential pest levels were partially reflected in yields. In both trials, maximum yields were in the 1 200- to 1 250-kg/ha range, but statistically significant yield differences were obtained only in GCVT II. Very low yields, a maximum of 656 kg/ha, were obtained from the GIET trial, with pod damage varying from 6 to 28 percent over the range of cultivars.

Since bruchid infestation in store is a very important source of loss, an attempt was made to determine if some cultivars were more resistant than others in a no-choice situation. A total of 55 cultivars were exposed to *Callosobruchus chinensis*. Some cultivars, notably ICRISAT 682 and JG 74, were only slightly damaged (3 and 6%, respectively), whereas others–such as ICRISAT 2763, GL 657, 850-3/27, and BG 203—were highly susceptible, with 90 to 97 percent of the peas showing typical exit holes. The apparent tolerance in some chickpea cultivars seems to be associated with the tuberculated surface.

[1] GCVT is Gram Cultivar Variety Trial; GIET is Gram Initial Evaluation Trial. These are trials conducted as part of the AICPIP.

### Looking Ahead in Chickpea Entomology

Relationships between insect damage and the two main chickpea types will be examined in greater detail. At the same time, damage on a range of cultivars will be studied. Methods for field screening of chickpea cultivars will be tested. In collaboration with ICRISAT's chickpea germplasm botanist, a preliminary screening of a large number of cultivars in an unsprayed block will be carried out so as to eliminate obvious susceptibles; if possible cultivars with advantageous characters for pest tolerance will be selected.

Damage assessment on survey will continue, and efforts will be made to visit chickpea areas outside India.

## Pathology

Three chickpea pathology projects were formally initiated in January 1975—(i) chickpea "wilt complex," (ii) developing techniques to screen for resistance and identify disease resistant lines, and (iii) seed pathology.

### Chickpea "Wilt Complex"

In chickpea, any dead plant is wrongly considered as wilted. Symptoms associated with different kinds of wilting/drying of chickpea plants noted during extensive surveys in different parts of India were thoroughly studied. Widespread prevalence of three disorders—which can be considered as important components of the so-called "wilt complex"—was observed. These are the stunt (virus?), the wilt caused by *Fusarium oxysporum* f. sp. *ciceri*, and the root rot caused by *Rhizoctonia bataticola*. In general, stunt was prevalent in all chickpea-growing areas of India, wilt was more prevalent in central and northern India.

and root rot in central and southern India. Other pathogens responsible for drying of chickpea plants were *Fusarium solani*, *Rhizoctonia solani*, *Operculella padwickii*, *Sclerotium rolfsii*, root-knot nematode, and a mosaic virus. In addition, insect and soil factors such as termites and salinity/alkalinity, etc., were observed to be operant at specific locations.

Major disease problems associated with some of the important chickpea research stations in India are (i) Coimbatore, *Macrophomina phaseoli (R. bataticola)*; (ii) Gulbarga, *(R. bataticola)*; (iii) Rahuri, (stunt); (iv) Jabalpur, (wilt); (v) Kanpur, (wilt and stunt); New Delhi, (stunt); Hissar, (stunt, termites, soil factors); Ludhiana, (root-knot); Gurdaspur, (wilt); and ICRISAT Center, (*R. bataticola*, wilt, and stunt).

The presence of stunt disease was discovered by ICRISAT scientists in 1974. This disease has often been confused with certain fungal diseases. No organism from stunt-affected plants has been isolated, but the causal agent has been transmitted by the aphid species, *Aphis craccivora*. For this reason, stunt is tentatively considered to be a virus problem.

Characteristic symptoms of stunt, wilt, and *R. bataticola* root rot are well understood; with these, one should be able to diagnose these diseases under field conditions.

### Disease Resistance

Since *Fusarium oxysporum* f. sp. *ciceri*, stunt virus, *Rhizoctonia bataticola*, and *Ascochyta rabiei* (blight) appear to be more widely prevalent than other pathogens, attention was focused on developing screening procedures for resistance to the four organisms. Techniques ("water culture" and "sand culture") for screening germplasm against *F. oxysporum* (and also *F. solani*) and *Ascochyta rabiei* have been standardized. "Water culture" and "sand culture" techniques for use with pigeonpea have been described (page 110); those for chickpea are similar, although minor variations must be observed. Under conditions at ICRISAT Center near Hyderabad, *Ascochyta* blight does not occur in nature. An "Isolation Plant Propagator" was used to make it possible to inoculate chickpea with *A. rabiei*. The technique has been used to successfully inoculate (*Ascochyta* spore suspension, 40 000 spore/ml) chickpea seedlings even during the summer, and will make it possible to screen germplasm and breeding material on a limited scale so that promising material may be identified before it is sent to areas where *Ascochyta* blight occurs in severe form naturally.

Screening chickpea germplasm for resistance to *F. oxysporum*, *F. solani*, and *Ascochyta rabiei* has been initiated. Attempts are being currently made to develop techniques to screen for resistance to *R. bataticola* and the stunt virus.

For field screening, two "sick plots" of 1.5 hectares each are being developed at ICRISAT Center. In one, inoculum of *F. oxysporum* is being added; in the other, stubble from diseased plants regardless of the pathogen are being added. Such an arrangement will make it possible to screen germplasm and breeding material against several pathogens under field conditions.

### Seed Pathology

During the year, facilities for following international seed-health testing procedures were established. Preliminary studies were carried out on microflora associated with chickpea seeds raised at ICRISAT Center. Fungi isolated from surface-sterilized chickpea seeds (cv ICRISAT-4953 or cv GW 5/7) were species of *Alternaria*, *Fusarium*, and *Phoma*. Concurrent tests, with the same seed lots, carried out at the Danish Institute of Seed Pathology in Copenhagen, revealed *Fusarium moniliforme*, *F. semitectum*, and *Phoma* sp. (a bit of doubt about the identity of *Phoma* was expressed). No fungus was isolated—either in ICRISAT's pathology laboratory or at Copenhagen—from the seeds of cv ICRISAT-4973 (L-550).

**Looking Ahead in Chickpea Pathology**

ICRISAT pathologists anticipate the following activities:

1. Screening of germplasm and breeding material for resistance to wilt (*Fusarium oxysporum*), root rot (*F. solani*), and Ascochyta blight under laboratory/screenhouse conditions.

2. Screening of germplasm and breeding material in the multiple-disease "sickplot."

3. Developing techniques to screen for resistance to root rot (*Rhizoctonia bataticola*) and chickpea stunt (virus?).

4. Continuing surveys to further understand the components of "wilt complex."

5. Continuing seed-health testing of the chickpea raised at ICRISAT Center, and a search to find ways to eliminate pathogens.

**Table 51. Protein percentage in chickpea germplasm samples grown at ICRISAT Center, post-rainy season 1974.**

| Source | Samples | Protein Range (DBC) |
|---|---|---|
| | (no) | (%) |
| India | 708 | 13.7 - 26.2 |
| Peru | 1 | 21.5 |
| Sri Lanka | 2 | 19.3 - 20.2 |
| Greece | 4 | 16.5 - 20.6 |
| Jordan | 5 | 16.5 - 20.1 |
| Tunisia | 6 | 15.2 - 21.9 |
| Portugal | 1 | 17.4 |
| Egypt | 4 | 17.0 - 17.9 |
| Cyprus | 5 | 17.6 - 19.9 |
| Morocco | 4 | 16.7 - 17.4 |
| Israel | 9 | 15.2 - 19.2 |
| Turkey | 10 | 15.6 - 19.0 |
| Pakistan | 10 | 17.4 - 20.6 |
| USA | 15 | 15.2 - 21.0 |
| Mexico | 14 | 15.4 - 17.4 |
| Syria | 5 | 16.1 - 19.5 |
| Iraq | 5 | 17.0 - 19.9 |
| Spain | 7 | 17.4 - 20.6 |
| USSR | 11 | 16.5 - 21.7 |
| France | 1 | 20.4 |
| Lebanon | 1 | 19.2 |
| Ethiopia | 10 | 17.0 - 19.7 |
| Algeria | 5 | 14.7 - 17.9 |
| Afghanistan | 20 | 15.6 - 21.7 |
| Iran | 145 | 14.2 - 23.3 |

## Nutritional Quality

A total of 1006 chickpea germplasm samples analyzed for protein content revealed ranges from 13.7 to 26.2 percent (Table 51). Samples from 25 countries were tested; those from India were most numerous and showed the widest range.

During the previous season, 11 accessions were grown at 3 different locations in India and different latitudes and altitudes (Table 52). Data on 10 of these (one gave spurious results) are presented to demonstrate the extreme effect of environment on seed size and protein content. Nitrogen per seed varied with seed weight within locations. Variety rank for protein was not consistent over locations, indicating a need for evaluating stability of this character in cultivars.

Amino acids were measured in five kabuli and five desi cultivars. The sulfur amino acids in desi type ranged from 2.07 to 2.95 percent of protein and the kabuli types 2.12 to 2.64 percent. With such a limited sample, the range observed is encouraging in respect to genetic variation for protein quality.

## Microbiology

Nodulation of chickpea at ICRISAT Center during post-rainy season 1975 was generally

Table 52. Results of analysis of 10 chickpea accessions grown at three locations.

| | Ludhiana (lat 31°N,elev 810 ft) | | | ICRISAT Center (lat 17°N,elev 1700 ft) | | | Lahaul Valley (lat 33°N,elev 10350 ft) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Minimum | Maximum | Mean | Minimum | Maximum | Mean | Minimum | Maximum | Mean |
| Protein (%) | 20.2 | 22.5 | 21.50 | 16.8 | 19.7 | 18.34 | 11.5 | 16.2 | 14.16 |
| Nitrogen (mg/seed) | 4.7 | 14.5 | 8.93 | 3.3 | 9.8 | 6.28 | 1.8 | 5.7 | 3.77 |
| 100-seed weight(g) | 13.4 | 40.6 | 26.04 | 11.0 | 32.8 | 22.40 | 9.9 | 24.0 | 16.61 |

effective, although in some black-soil watersheds early formed nodules senesced early and few effective nodules were present after flowering; plant growth was poor. In red soil, large differences in plant growth were associated with large differences in number and weight of nodules per plant. In the germplasm plantings, differences between lines in time to nodulation were observed. On survey trips in Andhra Pradesh, Maharashtra, and Madhya Pradesh, fields were found where chickpea plants were not nodulated. In other fields, some in Haryana, nodulation and plant growth were poor. This may reflect low *Rhizobium* populations in the soils or poor soil-moisture conditions. Large differences in growth between plants was again associated with differences in nodulation. On plants given one irrigation near flowering, new active nodules formed during pod set on roots growing close to the soil surface.

At ICRISAT Center nodules senesced soon after the plants flowered, whereas at Hissar—presumably because of the more favorable moisture regime—nodules were extremely large, and functioned during pod fill until final leaf senescence. Nodules on lines showing iron deficiency at Hissar were mostly senescent, while nodules on nonsusceptible lines were effective. *Rhizobium* strains from several locations have been isolated for testing their effectiveness in nitrogen fixation.

**Looking Ahead in Microbiology**

The numbers of soil-dwelling *Rhizobium* nodulating chickpea and pigeonpea and their effectiveness in nitrogen fixation will be determined for selected sites. Effect of soil type, season, and cropping pattern on *Rhizobium* populations will be studied, in order to determine response to inoculation with *Rhizobium*. The effect of seed inoculation with highly effective *Rhizobium* strains will be examined in field experiments, looking at the proportion of nodules formed by the inoculum strain, the persistence of the inoculum in soil, and effects on nitrogen fixation and yield. Even if inoculation produces only a 10-percent increase in yield, it will be an economic practice for farmers to adopt. Methods of producing inoculants and of inoculating seed to ensure successful nodulation will be sought.

Breeders' elite crossing material will be examined to see if there are lines superior in nodulation and nitrogen fixation. The heritability of these characters will then be determined so that ways of increasing nitrogen fixation by these crops can be explored.

# OILSEED

## Groundnut *(Arachis hypogaea)*

Groundnuts—as sources of human and animal feeds and as an economic crop—are one of the most important legumes of the semi-arid tropics. Of the world's total production, two-thirds is produced in the SAT. Yields are low, however, averaging only 500 to 800 kg/ha. Yields in the United States and some other areas can average around 2 500 kg/ha and in some areas will often be 5 000 kg/ha.

### ICRISAT Goals

ICRISAT's groundnut program can be summarized into three broad-based objectives:

To assemble, maintain, and screen a world collection of cultivated and wild *Arachis* material.

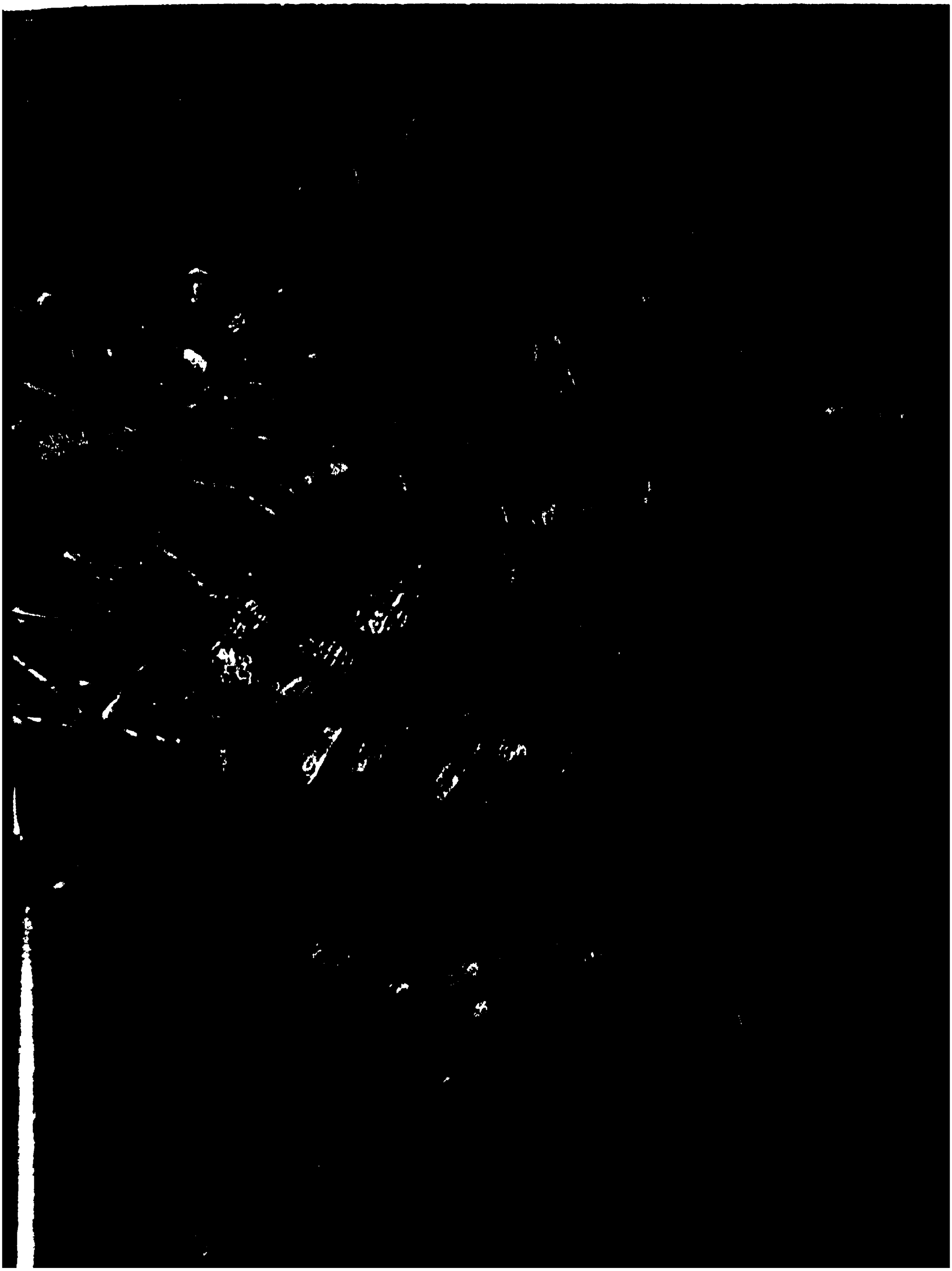
To seek, through breeding programs, to increase yields and incorporate resistance to important pests and diseases. Improvement of quality is also an important goal.

To provide introductions and segregating populations to all groundnut breeders in the SAT.

#### ICRISAT Center

The soil and climatic conditions at ICRISAT Center are ideal for groundnut research applicable to SAT agriculture. In addition to the major effort conducted under the rainfed situation of the normal season, irrigated crops will be produced during the post-rainy and hot dry seasons in order to facilitate the breeding program.

# GROUNDNUT



# Groundnut

A research submission covering all aspects of the proposed groundnuts program was presented to the ICRISAT Governing Board on 1 May 1976. The report emphasized the need of incorporating disease resistance to cultivars with high yield potential. The most important, or potentially most important, diseases affecting groundnuts throughout the semi-arid tropics are leafspots (*Cercospora arachidicola* and *Cercosporidium personatum*), rust (*Puccinia arachidis*), and yellow mold (*Aspergillus flavus*). Resistance to these pathogens is available in varying degrees of practical usability in cultivars of *Arachis hypogaea* or wild *Arachis* species.

## Breeding

### Germplasm

**India.** So far some 1 500 lines have been collected from local sources with the full cooperation of various research organizations in India. These cultivars are from exotic and from local sources and will be planted and evaluated in rainy season 1976. Some 2 785 entries, in a preliminary survey of the germplasm, have been listed as being available throughout India.

**Exotic.** The first 490 accessions released from the North Carolina State University collection have been grown under irrigation in the post-entry quarantine plots at ICRISAT Center. After weekly inspections by quarantine officials, many of the lines were released and harvested during May 1976. Considering the high temperatures prevailing during April and May, yields were remarkably good. Many of these accessions lack dormancy, so they will be replanted and assessed under normal rainy season conditions.

**Vegetative material.** Approximately 1 000 unrooted stem cuttings were received from the Reading University (UK) groundnuts project. These cuttings were successfully rooted in a screenhouse after quarantine examination in New Delhi. After weekly post-entry quarantine examination, the majority of the cuttings were released.

This material consists of interspecific crosses between the cultivated groundnut (*Arachis hypogaea* 2n = 40) and two wild species (*A. cardenasii* and *A. chacoense* 2n = 20) which have high-grade resistance to the two leafspot pathogens *C. arachidicola* and *C. personatum*.

The rooted cuttings include sterile triploid hybrids ($F_1$) and hexaploids ($F_1C_1$) with 60 chromosomes produced by colchicine treatment of the triploids. Plants produced from seed of the fertile hexaploids are also represented in this material ($F_2C_2$ and $F_3C_1$).

The cuttings are being planted in the post-entry quarantine area and they will be surrounded by leafspot-susceptible cultivars, such as TMV 2. Later in the season they will be scored for leafspot reaction.

### Seed of Interspecific Crosses

Two sets of seed are also available for leafspot-resistance evaluation. One set is of hexaploid material, containing $F_2C_2$ seeds, received from Reading University. The second set consists of $F_6C_6$ seeds resulting from a cross of *A. hypogaea* P.I 261942/3 and *A. cardenasii* which was treated with colchicine in the USA. Due to loss of chromosomes, these original hexaploids now have approximately 40 chromosomes. These seeds will be treated in the same manner as the vegetative material and exposed to a heavy inoculum of leafspots.

### Crossing Techniques

Although many of the disease-resistant cultivars have not as yet been received, plants of high-yielding cultivars have been sown in pots and will be used in training operators in groundnut-crossing techniques. Among the cultivars planted are Shulamith, Spancross, Florunner, Florigiant, M 13, and TMV 2.

### Coordinated Trials

Arrangements have been made to grow the All India Coordinated Groundnut Trials at ICRISAT Center in rainy season 1976. Seed has been received for the Coordinated Yield Trial, Initial Yield Evaluation Trial, and the Hand-Picked Selected (Confectionery) Trial.

## Entomology

The program on groundnut pests was confined to general surveillance of insect species on the crop and detailed examination of nurseries of introduced lines.

Damage by the white grub, *Holotricha* sp., was locally severe in red-soil areas. An important potential pest was the leaf webber, *Stomopteryx subseciveilla*. The larvae feed on young leaf tissue, often folding and webbing leaves at the apex of plants, causing stunted plant growth. In the time-of-planting trial, there were peaks of leaf-webber activity in mid-April and in September.

On irrigated crops grown out of season there was a high incidence of *Heliothis armigera* Hub. Sixty-two early instar larvae were recorded per 100 plants in May.

Pests causing minor damage included *Mylabris pustulata* Thunb, *Myllocerus undecimpustulatus* Fab., *Nezara viridula* var *viridula*, jassids, aphids, white flies, and thrips. Lepidopterous larvae—including *Spodoptera litura* Fab., *Crysodeixis chalcites* Esp., *Diacrissia obliqua*, and *Amsacta* sp—were also found.

## Pathology

### Fungi

The groundnuts time-of-planting trial (Farming Systems) was observed for disease incidence. Seed rot and seedling blight, caused by *Aspergillus* sp. and *Penicillium* sp. respectively, caused 20 percent mortality during the first planting in March 1975. Future plantings were treated with Agrosan GN seed dressing, at the rate of 3 g/kg of seed, and virtually complete control of the pathogens was achieved.

Leafspots, caused by *C. arachidicola* and *C. personatum*, and rust *(Puccinia arachidis)*, appeared in July in the plantings done in March, April, and May. Severity and prevalence increased until October 1975. The July plantings were severely affected in the seedling stages by both diseases. Mancozeb sprays (0.2%) did not give satisfactory control of either pathogen.

### Viruses

Bud-necrosis virus appeared in the last week of September on the 15 August and subsequent plantings. The 15 August and 30 August plantings showed approximately 10 percent incidence. A groundnuts plot in field RW-1 had more than 80 percent of the plants (var. TMV-2) affected.

The first symptoms are variable, but include chlorotic and necrotic ringspots with green islands which appear on newly opened leaflets 40 to 50 days after planting. These lesions gradually spread and necrotic streaks appear on the petioles and then on the stems. Soon afterwards the terminal bud becomes necrotic, bends downwards, and dies. Proliferation of axillary branches occurs and their leaves are reduced in size, and mottling, vein clearing, curling, and marginal chlorosis appear. The entire plant becomes stunted. Infected plants produce fewer and smaller pods. The kernels are wrinkled and small with dark lesions on the testa. Sometimes all the buds become necrotic and the plant dies.

Despite many attempts to isolate fungi from infected tissue, it appears that there is no association of another primary pathogenic organism with bud necrosis.

The virus was readily transmitted by grafting. Symptoms appeared in 12 to 15 days after grafting in warm weather but required 30 to 40 days to appear when the weather was colder. The virus can be mechanically transmitted using cold potassium phosphate buffer (0.05 M; pH 8.5), antioxidants (particularly 0.02 M 2-mercaptoethanol), and 300- to 600-mesh carborundum.

Cowpea (*Vigna unguiculata*) is a good local lesion assay host. Five to 7 days following inoculation, two types of local lesions—chlorotic and necrotic—are seen. Mixed types of local lesions, chloronecrotic or necrochlorotic, also appear. The virus becomes systemic in cowpea and new leaves are reduced in size; in extreme cases the whole plant wilts.

The virus does not appear to be transmitted through the soil or by seed. Although more-critical tests are needed, the present study shows that bud necrosis was not transmitted by *Aphis craccivora* Koch or two unidentified leaf hoppers. Mechanical transmissions to cowpea were positive when extracts of groundnuts leaves and stems were used but were negative with extracts of groundnuts roots, flowers, and immature seeds.

The following host species produced local lesions when mechanically inoculated—*Gomphrena globosa*, *Chenopodium amaranticolor*, *C. quinoa*, *Zinnia elegans*, *Cucumis melo*, *Cajanus cajan*, *Phaseolus vulgaris* (var Bountiful), *Vigna mungo* (var H-21), *Vigna radiata*, *Datura stramonium*, *Lycopersicon esculentum* (var Perfection, but not Pusa Ruby or Marglobe), *Nicotiana tabacum* (var Samsun NN and Xanthi-nc), *Nicotinia glutinosa*, and *N. glutinosa* × *N. Clevelandii*. In *C. melo*, *P. vulgaris* *V. mungo*, *V. radiata*, *L. esculentum* (var Perfection), and *N. glutinosa* × *N. Clevelandii* the virus became systemic and recovery assay on cowpea var C-152 was achieved.

Freshly extracted crude groundnut sap at room temperature (30 to 32°C) produced 44.4 local lesions per leaf on cowpea (var C-152). Inoculations after one hour at room temperature produced an average of 24.8 lesions per leaf, but inoculations made after 4 hours at room temperature produced only 0.8 lesions per leaf; subsequent inoculations produced no local lesions at all.

## Microbiology

In the black soils groundnuts nodulated sparsely and appeared to be nitrogen deficient. The nodules senesced early, but this was not related to moisture availability as irrigated groundnuts had nodules senescing at the flowering stage. In the red soils, more nodules were formed on the plants and although they were generally effective they also senesced early. Early senescence may be related to high plant densities. Local and exotic *Rhizobium* strains will be tested for their usefulness in inoculants.

## Looking Ahead in Groundnut Improvement

It is anticipated that many more accessions will be received from local and exotic sources for addition to the ICRISAT germplasm collection during the coming year. ICRISAT breeders will continue to train operators in groundnut crossing techniques, and will begin improvement breeding experiments when superior lines and sources of disease and pest resistance in current plantings are identified. Surveys of groundnut insect pests will continue in order to determine relative importance and to develop control programs. Detailed studies of "bud necrosis virus" will continue, as will rapid screening of all germplasm material for resistance to this disease. The collection will also be screened for sources of rust resistance. ICRISAT microbiologists will continue with their investigations of various aspects of nodulation by *Rhizobium*.

# FARMING SYSTEMS

The goals of ICRISAT from the beginning have embraced development of improved systems of farming. In general, the goals of the Farming Systems section parallel those long-range goals of ICRISAT—to increase food production in the SAT, and to make it more reliable from season to season and year to year.

Specifically, the goals of the Farming Sys-ems research programs can be presented in ree statements—

—to aid in generating economically viable bor-intensive production technology which akes a better use of the productive potential f resources while at the same time conserving nd improving resources.

—to assist in development of technology for nproving land and water management and esource conservation systems which can be implemented and maintained during the extended dry seasons, thus providing additional employment to people and better utilization of available manpower.

—to assist in raising the economic status and quality of life for the people of the SAT by aiding in the development of systems of farming which will increase and stabilize agricultural output.

At any location, these objectives must be accomplished by providing optimum conditions for rainy and post-rainy season cropping through proper management of the soil and of the total precipitation that falls on the land and by better utilization of the improved environment through more-productive cropping systems. In some areas this will also require collection and storage of runoff and the efficient utilization of storage and groundwater.

# FARMING SYSTEMS

# Farming Systems

Rainfed agriculture has failed to provide even the minimum food requirements for the rapidly increasing populations of many developing countries in the SAT (Semi-Arid Tropics). Although the reasons for this are many, a primary constraint to agricultural development in the seasonally dry tropics is the lack of suitable technology for soil and water management and crop production under the undependable rainfall conditions. The severity of the constraints is amplified by the generally high evaporative demands and, in many areas, by soils of shallow depth with limited water-holding capacity.

During the past 25 years, populations in many areas of the SAT have doubled; farmers have therefore attempted to increase production. Since there has been no substantial increase in per-hectare yields during this period, the result has been a tremendous increase in cropped area and often in livestock numbers. Thus, steeper and more-erodable lands are frequently being over-cropped and over-grazed and forest lands have been denuded, causing permanent damage to vast areas. The decreasing productive potential of the land in turn increases the quest for more land. To break the vicious circle, more-stable forms of land use—forms which preserve, maintain, and better utilize the productive capacity of available resources—are urgently needed.

To aid in the attainment of its objectives across diverse agro-climatic regions of the SAT, the Farming Systems research program is involved in the following activities:

1. Assembly and interpretation of existing base-line data in several areas of science relevant to agriculture in the SAT.

International assembly and communication of basic and applied research results as related to farming systems in the SAT.

Basic or supportive research on research methodology, agro-climatology, hydrology, soil physics, soil fertility and chemistry, farm machinery, land and water management, agronomy, economics, etc.

4. Simulation or systems analytic studies based on climate, soil, and economic information to predict the potentials of new cropping patterns, cultivation, or resource-management practices.
5. Organization of international cooperative trials to rapidly gain information about the performance of a given practice or technique over time at the same location and/or across locations.
6. Training of researchers for national research institutes.
7. Research on resource-management techniques and agricultural practices at ICRISAT Center and selected bench-mark locations.

The Farming Systems research program consists of four complementary components:

1. Research on production factors.
2. Resource utilization research on an operational scale.
3. Cooperative research with national and regional organizations.
4. Training programs in Farming Systems research and development.

Research on production factors involves applied or basic studies of specific segments of the entire farming system. Although some of these experiments will not give complete answers with regard to questions of actual implementation on a farm-size scale or on the economics involved, it is necessary to work under carefully controlled and manageable conditions to find "leads,"—in other words, to determine "what" to do.

In resource-utilization research, the central objective is to make the best use of the rain that falls on a given area. To study water as an input, small natural watersheds relating in size to actual farm holdings were chosen as the unit for research. Since water is the major constraint to agricultural development in the SAT, it is expected that the watershed will, in time, become the focus for resource development and utilization.

The watershed-based studies encompass investigations on resource development, management, and conservation; water-balance studies; and research involving the integration of improved soil-, water-, and crop-management technology. Efficient use of human labor and draft animals and elimination of bottlenecks are considered important objectives. On the research watersheds, alternative farming systems are simulated and then carefully monitored on a field-size scale to evaluate such factors as water-utilization patterns, production effects, resource conservation, and economics. Therefore, the watersheds also serve as "pilot plants" for studies on the integration and evaluation of a wide range of management technology on an operational scale. This operations research provides the setting to determine "*how*" to implement an improved technique under near real-world conditions.

# PRODUCTION-FACTOR RESEARCH

## Agro-climatology

A quantitative understanding of the agricultural climate of any given region is a prerequisite for developing a sound farming-systems research program (as well as a crop-improvement program) and for establishing guiding parameters for agricultural development. Probability techniques are used to construct models for analyzing long-term rainfall data in relation to evapotranspiration and soils of various moisture-holding capacities. This information is then used to suggest potentially optimum cropping patterns to fit the various environments. Also, tentative data on water utilization by crops under the best cropping-system and land-management techniques envisaged and on losses in terms of evaporation, runoff, and deep percolation are generated. It is expected that these activities will contribute substantially in delineating the most-rewarding areas for agricultural research, thereby reducing the time required to attain results.

The collection and analysis of weather data at the ICRISAT Center has also been one of the responsibilities of the Agro-climatology subprogram.

### Weather

**Rainfall.** Daily rainfall during rainy season 1975 (Fig 1) shows the season to be one of the wettest on record; a total rainfall of 1 045.5 mm was recorded at the ICRISAT agro-meteorological observatory, and 1 265.7 mm was measured at one boundary of the Center. In only 4 of the past 50 years has annual precipitation exceeded 1 000 mm.

Monthly rainfall during the past 4 years, as well as the long-term averages, are plotted in Figure 2. Comparisons between years, as well as studies of the rainfall patterns within years, show that many extreme situations occurred. The observed distributions quite vividly illustrate the uncertainty and lack of consistency in climate, especially rainfall, in the SAT.

Rainy season 1975 was characterized by relatively few high-intensity storms; the five highest-intensity storms and the total quantities of rainfall received are presented in Figure 3. Two storms stand out in particular; a maximum daily rainfall of 155.7 mm was recorded on 9 September. Another large storm of 83 mm was received on 24 September; the maximum intensity of this storm amounted to 88 mm/hr, the highest so far observed at ICRISAT Center. Surprisingly, the frequencies with which given rainfall intensities have been exceeded during the past 4 years are substantially in excess of reported probabilities.

**Air and soil temperatures.** Weekly averages of maximum and minimum air temperatures (Fig 4) reveal a maximum temperature of 43.6°C (108.7°F) was recorded on 14 May 1975 while a minimum temperature of 6.9°C (44.5°F) was recorded on 26 December 1975.

In examining trends in soil temperatures (Fig 5) it is interesting to note the great variation in diurnal temperatures at shallow depths and also the extremely high temperatures near the soil surface, exceeding 50°C on some dates.

**Evaporation.** Open-pan evaporation rates were highest (Figure 8) during the month ol May; maximum daily evaporation, 19.2 mm, was recorded on 25 May 1975. Extreme fluctuations occurred during rainy versus dry days in the rainy season. On some rainy days in August, evaporation rates as low as 1.7 mm/day were recorded; the evaporation rates during subsequent dry periods were several times higher (up to 8 mm/day).

### Characterization of the Agricultural Climate

A simulation study on the quantification of the moisture environment for crop growth was conducted, using the environment at ICRISAT Center to test the methodology. A few important aspects are presented in the following paragraphs.

**Dependable rainfall.** Annual and monthly rainfall varies greatly. The wettest year on record during the period 1901 to 1970 received 1431 mm; the driest year, 457 mm (in 1972, only 379 mm of rain fell).

Dependable precipitation is defined as rainfall of a specified minimum probability of occurrence. A 75-percent probability is generally accepted as a reasonable risk value for agricultural-decision purposes. The dependable precipitation at 75-percent probability for the early rainy period (18 Jun - 15 Jul) is 85 mm, for the mid-rainy (16 Jul - 12 Aug) 95 mm, for the period 13 August to 9 September, 81 mm, and from 10 September to 8 October, 72 mm. The amount of dependable rainfall in the post-rainy and hot dry seasons is very small. The total annual dependable precipitation (at 75% probability) is 648 mm against a mean annual ·ınfall of 789 mm.

**nd preparation and sowing.** Based on rainfall alysis, a calendar of farm operation for :d-bed preparation and planting dates was veloped (Table 53). On deep black soils, the tial land preparation should commence mediately after the harvest of the last crop in preceding season so that only secondary age has to be carried out in the pre-sowing iod. Unless this is done, the opportunity for ablishing a crop on these soils during the ny season may be lost.

**Length of the growing season.** A computerized water-balance model was used to derive estimates of week-to-week changes in available moisture in relation to potential evaporation demands, using weekly rainfall as an input and estimated evapotranspiration as withdrawals. Through this simulation study, the duration of the crop-growing period as determined by total available moisture has been estimated (Table 54). Soil type plays a dominant role in defining the growing periods in a given rainfall situation.

**Variability of available profile moisture in three soil types.** A reliable estimate of intraseasonal probabilities of water deficits is provided by estimates of soil-moisture variations occurring over the growing season. The medium amounts of available water present in the root profile of three soil types [low AWC (available-water storage capacity) and high AWC] made from water-balance studies are plotted in Figure 25.

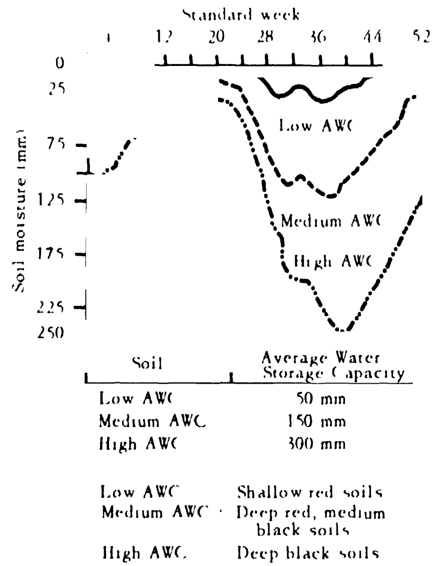



**Figure 25. Soil moisture storage in shallow and deep red soils and in medium-deep and deep black soils (based on data recorded in Hyderabad, 1901-1970).**

**Table 53. Suggested calendar for seedbed preparation and sowing for the rainy season.**

| Farming operation | Soil type | | |
|---|---|---|---|
| | Heavy black | Light black | Red |
| 1. Preparatory tillage | before 18 Jun | 4 Jun - 25 Jun | 11 Jun - 25 Jun |
| 2. Seed-bed preparation | before 18 Jun | before 2 Jul | before 2 Jul |
| Sowing[a] | Dry-planting | Planting in moist seedbed | |
| (i) Crops tolerant to drought at seedling stage | 18 Jun | After 2 Jul | After 2 Jul |
| (ii) Crops sensitive to drought at seedling stage | 25 Jun | After 2 Jul | After 2 Jul |

[a] Planting dates should be advanced one week if more than 10 mm rainfall is received in week 23 (4 - 10 Jun) and/or week 24 (11 - 17 Jun).

**Table 54. Length of the rainy season growing period in three soils having different available water-storage capacities (AWC)**

| Probability | Available root profile water-storage capacity[a] | | | | | |
|---|---|---|---|---|---|---|
| | Low (50 mm) | | Medium (150 mm) | | High (300 mm) | |
| | period[b] | weeks | period | weeks | period | weeks |
| Mean | 25 Jun - 28 Oct | 18 | 25 Jun - 18 Nov | 21 | 25 Jun - 23 Dec | 26 |
| 90% | 25 Jun - 30 Sep | 14 | 25 Jun - 21 Oct | 17 | 25 Jun - 18 Nov | 21 |
| 75% | 25 Jun - 7 Oct | 15 | 25 Jun - 4 Nov | 19 | 25 Jun - 2 Dec | 23 |
| Median | 25 Jun - 21 Oct | 18 | 25 Jun - 18 Nov | 21 | 25 Jun - 23 Dec | 26 |
| 25% | 25 Jun - 11 Nov | 21 | 25 Jun - 9 Dec | 24 | 25 Jun - 14 Jan | 29 |
| 10% | 25 Jun - 25 Nov | 22 | 25 Jun - 23 Dec | 26 | 25 Jun - 4 Feb | 32 |

[a] The shallow red soils exemplify a low-AWC situation; the deep red and medium deep black soils, a medium-AWC situation; and the deep black soils a high-AWC situation.

[b] From the sowing rains up to the week when the availability of profile moisture reduces EA/PE to 0.5 (EA and PE = actual and potential evapotranspiration).

The amount of available moisture in the low AWC soils does not exceed 60 to 70 percent of the total AWC; there is a marked decrease in the amount of available water in the first half of August (to less than 25 mm). Since the evapotranspiration demand during the rainy season often exceeds 25 mm per week, a break in the continuity of rains exceeding one week would be quite hazardous to crops in low-AWC soils.

These determinations emphasize that to increase and stabilize crop production in such soil regions, there is a need for developing alternate water sources to break intraseasonal droughts. One alternative is to collect runoff during periods of excess rainfall and to reuse the collected water through an on-farm water-storage and -application facility.[1]

**Selection of suitable crops and cropping patterns.** A systems-analysis technique has been developed by which the probabilities of water available to a crop over the growing season are estimated. These estimates are then compared with the water requirements of crops and varieties within crops. The fit of the water-availability estimates in different soil types with the water demand by a crop gives an idea of the suitability of that crop in a given soil-climate system. An example of the fitting of long- (130-150 days), medium- (100-110 days), and short- (65-70 days) duration crops appears in Figures 26 and 27.

This technique gives an integrated index of the rainfall, soil, and evapotranspiration. Since it quantifies the crop-growing period and its characteristics in terms of water stress or sufficiency periods, the selection of crops with the required phenological characteristics for any specific location becomes an easier process. This approach is expected to substantially reduce the time and effort required to suggest suitability of crops or genotypes for various locations. It also permits identification of ecologically similar isoclimes, thus facilitating the transfer of appropriate farming-systems technology.

**Implications.** An application of this type of analysis can be illustrated with sorghum. Sowing rains are received in the last week of June (delayed planting increases shoot-fly risk). Traditional varieties (130-150 days) will flower in late September and reach physiological maturity in late October or early November. The crop will be caught in a water-deficit situation at the reproductive stage in most years on low-AWC soils; in medium- and high-AWC soils the crop will normally be well supplied with water. Shorter-duration varieties (90-100 days) will flower in the last half of August and

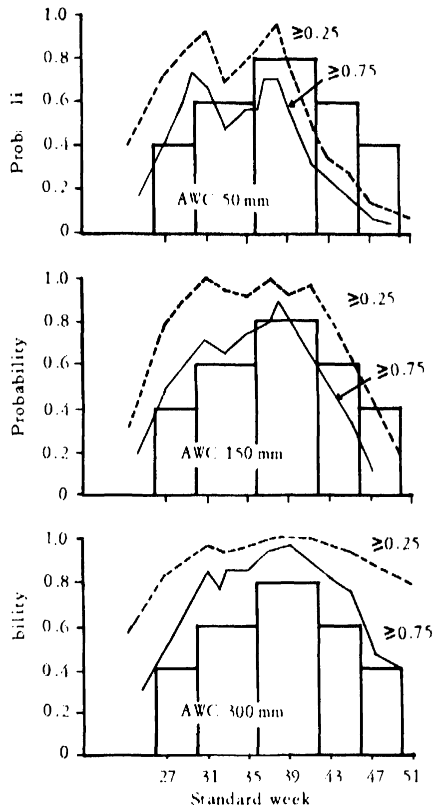



**Figure 26. Fitting of a long-duration (130 to 150 days) crop in three soils commonly found in SAT areas (bars represent water requirement and curves represent water availability at two probability levels).**

reach physiological maturity in early October. Such varieties may frequently be subject to moisture stress due to drought in August. Considering precipitation probabilities at physiological maturity, the longer-duration sorghum will be caught in heavy rainfall in 3 years out of 10, the shorter-duration material in 5 or 6 years out of 10. Thus, while present varieties are subject to serious risk, shorter-duration genotypes may not provide a better alternative; the post-rainy season on high-

[1] The All-India Coordinated Research Project for Dryland Agriculture and ICRISAT are developing appropriate technologies in this section. The application of small quantities of water should be made on the basis of probabilities of rainfall.

AWC soils would seem more appropriate for sorghum.

### Looking Ahead in Agro-climatology

After improving the present simulation models, it will be feasible to quickly analyze climatic and soils data from any given area and then to use this information in quantifying the moisture environment and then using this to determine the range of most-promising crops, varieties, and cropping systems to be selected. During the coming year, this will be a priority area of work.

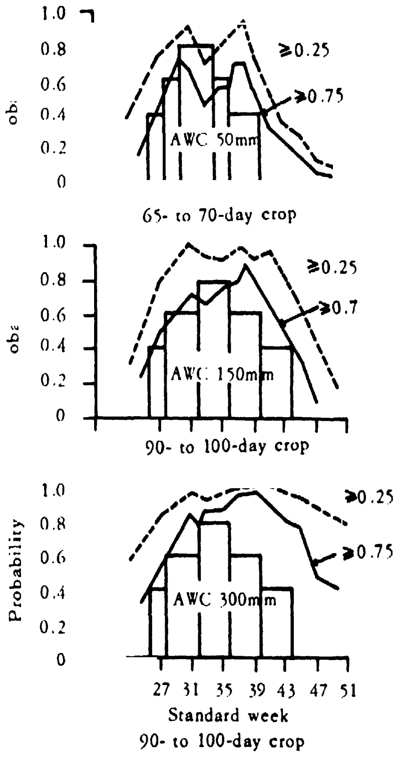



**Figure 27. Fitting of short- (65 to 70 days) and medium- (90 to 100 days) duration crops in three soils commonly found in SAT areas (bars represent water requirement and curves represent water availability at two probability levels).**

## Hydrology

The objectives of the hydrology subprogram are:

1. The quantification of runoff probabilities and erosion prevailing in various agro-climatic zones of the SAT.

2. The determination of the effects of various management treatments in watersheds upon surface and groundwater hydrology.

3. The development of hydrologic models and simulation programs for the interpretation and extrapolation of research findings to major agro-climatic zones of the SAT.

Since all hydrologic studies are presently conducted on watershed units at ICRISAT Center, these will be discussed under the section on "Resource Utilization Research."

### Development of a Runoff Sampler

Observations of sediment distribution across cross-sections of a parshall flume showed that turbulence resulted in a relatively uniform distribution at the beginning of the diverging section. Once this was determined, a small orifice of 4 mm in diameter was constructed at the base of the diverging section of the flume. A small sample of runoff was led out through a copper tube to a runoff sampler (Fig 28). The sampler consists of a clock located at the center of a circular channel 40 cm in diameter. The channel is about 2.5 cm wide and 2.5 cm high, with 50 small vertical independent partitions. An arm is fixed to the clock and this arm turns in a circle directly over the channel. Using a flexible plastic pipe, the runoff sample is led to the partitions in the circular channel. Each partition has a small pipe connected to the base of the chamber that carries the runoff sample to labeled bottle attached at a somewhat lower level.

The clock and gear ratio completes a revolution during each 5-hour cycle This permits sampling of runoff with individual samples collected at 6-minute intervals over a maximum period of 5 hours Once the samples are collected, they are related to the runoff hydrograph Runoff volumes for each 6-minute period are computed from the runoff hydrograph, and the corresponding figures of soil loss from individual samples are used to calculate precisely the total soil loss over each 6-minute interval, as well as cumulative over the entire duration of the runoff event

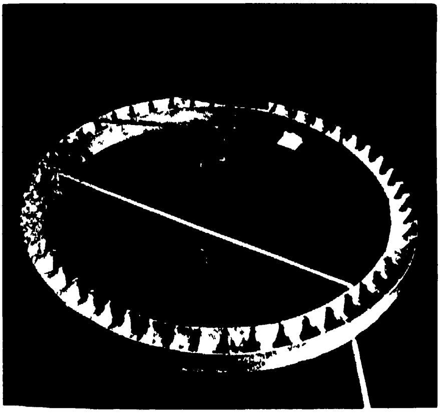


*Figure 28 Automatic runoff sampler for measuring erosion*

### Looking Ahead in Hydrology

The collecting of available hydrologic data from various agro-climatic zones in the SAT will receive increased attention in the coming year Cooperative research (initially within India) will be extended (see Cooperative Research) Now that several years' ICRISAT data is available, efforts will be made to test and adapt available hydrologic models and simulation programs for purposes of prediction

## Soil Physics

The soil profile is the primary water-storage element of the hydrologic cycle amenable to management by the farmer Therefore, efforts to manage and control the intermittent and variable natural water supply (rainfall) must give major attention to the dynamics of water in the root zone An understanding of the physical properties of soils is essential in order to manage soils so that they provide the best moisture environment for crop production The extent and properties of root systems have an important bearing on the water actually available to the plant The soil-physics subprogram is focused on the quantitative characterization of water retention and flow in the soil profile in relation to plant growth

### Water Infiltration on Red Soil

Three determinations of total water infiltration and infiltration rates were made on areas planted to sorghum under flat narrow-ridged (75-cm) and broad-ridged (150-cm) cultivation on red soil The infiltrometers used consisted of a square metal frame 1 5 m on a side and 45 cm deep A buffer zone was created by a second metal frame (2 44 m on a side) placed around the actual infiltrometer Both metal frames were driven into the soil to a depth of about 15 cm The infiltrometers and buffer zones were then filled with water to an initial depth of 25 cm Water-depth readings were taken at short intervals in the initial stages after filling and at longer time-intervals when the infiltration rates decreased

Cumulative infiltration is plotted in Figures 29 and 30 Infiltration on broad- and narrow-ridged areas exceeded the values obtained in flat-planted areas Since the red soils are extremely variable in depth and in surface characteristics and since measurements were made at few locations, it has not been possible to arrive at final values for the infiltration rates. At one location, the total amount of water infiltrated under broad ridges and narrow ridges during the initial 4 hours of the experiment exceeded the values observed under flat planting by 5.2 and 2.6 cm respectively; at another location, similar values of 6.9 and 4.8 cm respectively were measured (Fig 29, 30). At this latter location, the infiltration rates after 4 hours of ponding were 1.5, 1.8, and 2.0 cm/hr respectively under flat, narrow-ridged, and broad-ridged conditions; it thus appears that infiltration rates under narrow- and broad-ridged conditions were substantially higher

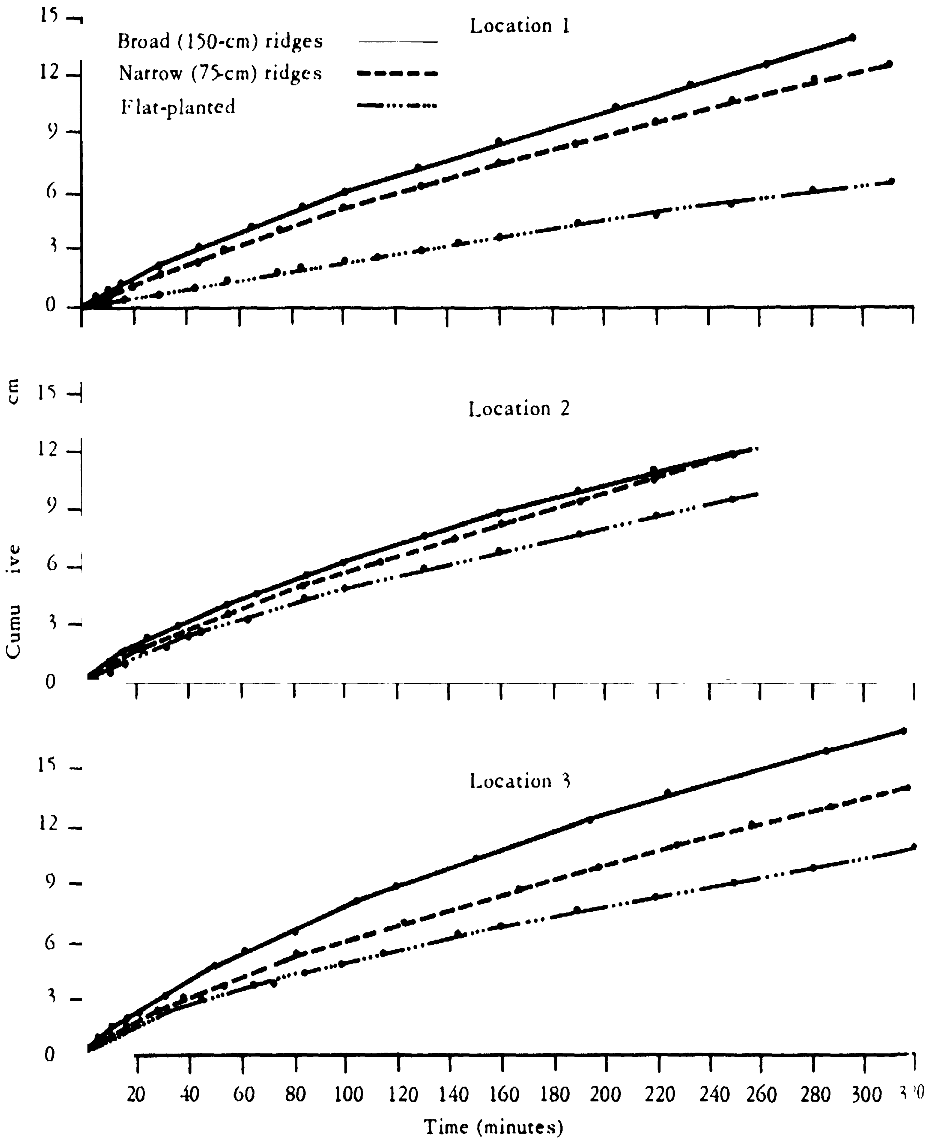



**Figure 29. Cumulative water infiltration at three locations on red-soil watershed RW1 D at ICRISAT Center.**

than those under flat planting for a considerable period(<2 days) after the beginning of the experiment.

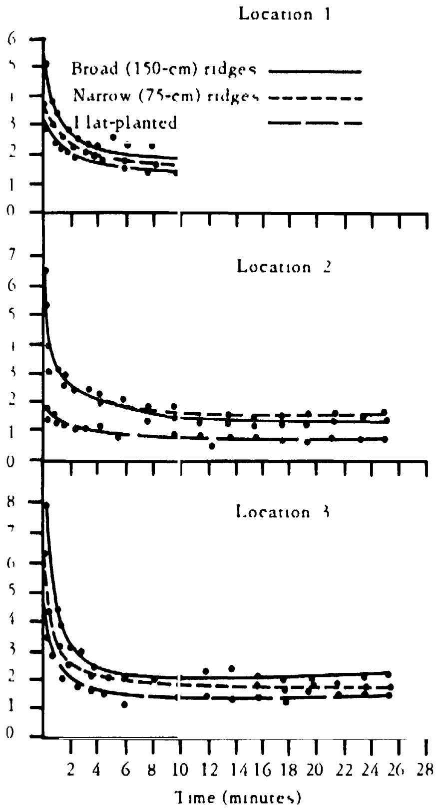



Figure 30. Water infiltration rates in broad-ridged, narrow-ridged, and flat-planted soil at three locations on red-soil watershed RW1D at ICRISAT Center.

### Rooting Patterns of Important Crops

The rooting patterns of maize and sorghum were studied on red and on black soils by determining "root density," which is defined as the average total length (cm) of roots per $cm^3$ of soil. The sampling procedure consisted of taking five to eight soil samples at three locations immediately below the sorghum or maize crown from successive 15-cm soil layers to 60 cm depth and then from successive 30-cm layers to 210 cm and 120 cm on black and red soils, respectively. The collected soil cores were soaked and washed to separate the roots and the composite length of root segments was recorded. The soil was too wet during the monsoon season to permit sampling; some of the data collected during the post-rainy season are summarized in Table 55.

On black soil, the root density observed in the surface 30-cm soil layer was greater for maize than for sorghum, while below the 30-cm depth the reverse was true; 18 and 6.8 percent of the roots were found at a depth greater than 90 cm for sorghum and maize, respectively. On red soils, maize had a higher root density at all depths than did sorghum; root-density profiles for the two crops were similar. In both crops a greater percentage of roots was found in the surface 30-cm soil depth on red soil than on black soil, while below this depth the relative root distribution was similar.

### Looking Ahead in Soil Physics

The emphasis on quantitative characterization of the moisture environment for crop growth will be continued. Dependable, simple, and rapid methods for the quantification of this phase of the environment are essential to studies in agricultural climatology and resource-utilization research, particularly in view of the initiation of cooperative farming-systems research activities across widely divergent regions in the SAT.

Substantially more attention will be given to questions regarding the biological consequences of the dynamic moisture regimes which characterize the SAT. This work will focus on the quantitative elucidation of the role of water in crop production. This research will be directed at the soil-plant-atmosphere system which, because of its highly dynamic nature, must be treated as a functional unit rather than as separate components.

Table 55. **Root-density profiles for mature maize and sorghum growing on red and on black soils at ICRISAT Center.**

| | SORGHUM | | | | MAIZE | | | |
|---|---|---|---|---|---|---|---|---|
| | black soil | | red soil | | black soil | | red soil | |
| Soil depth | root density | % of total | root density | % of total | root density | % of total | root density | % of total |
| (cm) | $(cm/cm^3)$ | (%) | $(cm/cm^3)$ | (%) | $(cm/cm^3)$ | (%) | $(cm/cm^3)$ | (%) |
| 0-30 | 0.23±0.07 | 40.7 | 0.16±0.01 | 63.0 | 0.32±0.09 | 57.4 | 0.25+0.06 | 61.3 |
| 30-60 | 0.18±0.05 | 28.6 | 0.08±0.02 | 30.3 | 0.14±0.04 | 29.8 | 0.02±0.02 | 30.8 |
| 60-90 | 0.06±0.01 | 12.6 | 0.01±0.01 | 4.2 | 0.02±0.02 | 5.8 | 0.02±0.01 | 5.6 |
| 90-120 | 0.02±0.01 | 5.6 | 0.01±0.00 | 2.5 | 0.01±0.01 | 2.8 | 0.01+0.00 | 2.3 |
| 120-150 | 0.02±0.01 | 5.1 | stony murram | | 0.01±0.01 | 2.3 | stony murram | |
| 150-180 | 0.02±0.01 | 4.0 | stony murram | | 0.01+0.01 | 1.2 | stony murram | |
| 180-210 | 0.01±0.01 | 3.4 | stony murram | | 0.00±0.01 | 0.5 | stony murram | |

## Soil Fertility and Chemistry

Crop production in the SAT is undertaken largely in a context of actual or incipient nutrient deficiency. While one looks forward to increased use of fertilizers, the efficient utilization, recycling, and conservation of the natural soil-nutrient resources is of profound importance to the productivity and stability of farming systems in the SAT. Thus, the Soil Fertility and Chemistry subprogram must be concerned with nutrient cycling in alternative cropping systems under different management practices and in varying soil-climatic environments, with nutrient transformations, and with the balance sheet of nutrient gains and losses.

### Fertilization Experiments

Fertilization studies with improved varieties from the All-India Coordinated Crop Improvement programs have been conducted during the past 3 years. From these preliminary studies, deficiencies of nitrogen, phosphorus, and zinc were confirmed in the red and in the black soils at ICRISAT Center. The magnitude of nitrogen response in black soils was in the following order: maize, sorghum, pearl millet, and sunflower; in red soils the order was sorghum, castorbeans, pearl millet, safflower, and sunflower. Experiments in 1975 showed no positive effect on sulfur-coated urea of "N-serve" (a nitrification inhibitor) in comparison with standard applications of urea.

The magnitude of the phosphorus deficiency was greatest in the red soil and the order of response was: sorghum, maize, pearl millet, safflower, sunflower, chickpea, and pigeonpea.

A potassium application has been included during the past 3 years, but neither deficiency or response to potassium application has been observed on any crop on either soil. Massive doses of potassium (up to 450 kg/ha) were tried in 1975; again there was no consistent response to K application on either soil.

Zinc deficiency of zinc-sensitive plants — maize, pearl millet, and sorghum— was found on the red and on the black soils, particularly in areas which had been heavily eroded or where old field bunds had been removed in the reclamation process. Zinc deficiencies were first observed in 1973, and were corrected by a spray (0.5% solution) of zinc sulphate. In the same year, a small experiment was conducted on a zinc-deficient area to determine the quantity of zinc required for complete correction on sensitive crops. It was found that 10 kg/ha of Zn incorporated in the soil was sufficient to correct the deficiency.

#### Looking Ahead in Soil Fertility and Chemistry

Studies aimed at evaluating seasonal changes in nutrient status under alternative cropping systems and experiments on different nitrogen levels in legume-intercropping systems, as well as on slow-release nitrogen sources, will be continued. A new 4-year experiment involving methods of timing of application of low-cost phosphate on red soils is being initiated.

## Farm Equipment

Animals are, and will be for a long time to come, the primary source of power for many farms in most SAT regions. The Farm Equipment subprogram will therefore direct a considerable portion of its resources towards the generation of more-efficient systems for the use of draft animals and the development of improved animal-drawn implements. This does not, however, exclude efforts to integrate mechanical power into systems of farming wherever this appears to be required and may be economically and socially feasible. Even then, the emphasis will generally be on the development of power-equipment packages which are rather small in scale that will fit situations where capital is limited. The development and adaptation of large high-powered prime movers and associated machinery will be left to those research institutes and manufacturers best equipped to satisfy these requirements.

#### Multiple-use Tool Carriers and Planters

Several types of tool carriers (also called versatools or polyculteurs) were collected at ICRISAT Center. These different units were then tested on red and black soils in operations such as plowing, ridging, sowing, and cultivating. It was found that the "Nolle" polyculteur performed well and had the required flexibility to adjust to various crop-row widths and spacings of graded furrows, a feature lacking in some of the other models. This carrier is used in remaking broad graded ridges by plowing soil in opposite directions on red soil (Fig 31). Efforts are now underway to decrease the cost of this tool carrier by minor modifications in design.

The broad-ridged (150-cm) system necessitated the design of a new ridger. Two ridgers were attached to a multiple tool carrier at a distance of 150 cm with a wooden float transporting material from the edge of the furrow to form the broad ridge (Fig 32). It was found that quite satisfactory ridges could be attained in a single operation. Forming the ridge in one operation made possible the working of more than one hectare in an 8-hour working day. Adaptations with regard to the lifting mechanism resulted in a more-efficient operation, requiring one pair of bullocks and only two laborers.

Without good stands at the beginning of the season, reasonable yields cannot be expected. Observed variation in terms of within-row spacing justified further work aimed at obtaining a greater degree of control with regard to planting depth and uniformity of seed rate. Most of the Indian seed drills are designed for wheat; such machines do not adequately control plant stands for crops such as sorghum and maize. Therefore, several models of unit planters, based on seed plates, were collected and tested. One model (Fig 33) appears to work reasonably satisfactorily planting a millet-pigeonpea intercrop. This model will be further

*Figure 31. Maintaining broad ridges with bullock-drawn plow.*

tested and modified, if necessary, during planting in the rainy season 1976.

### Looking Ahead in Farm Equipment

As soon as additional staff becomes available, the Farm Equipment subprogram will direct its primary activities to the exchange of all available information of new developments in agricultural machinery and power as they relate to SAT agriculture. Efforts to precisely describe the requirements of various operations and the adaptation of machinery to fulfill these will be intensified. Where required, new designs for particular operations will be generated.

## Land and Water Management

A general characteristic of farming systems now employed is that only a relatively small portion of the rainfall is used for crop production–in other words, total annual rainfall substantially exceeds "effective rainfall."[1] Existing cropping systems are inefficient with regard to the quantities of food produced in relation to the amount of water used as evapotranspiration, i.e. "water-use efficiencies"[2] are low.

[1] "Effective rainfall" is defined as the percentage of the annual rainfall actually used as evapotranspiration by a soil-crop complex.

[2] "Water-use efficiency" is defined as the agricultural production (kg or money) in relation to the actual crop-related evapotranspiration (cm).

*Figure 32. A tool carrier making broad ridges and furrows.*

Low effective rainfall, combined with low water-use efficiency, result in very low "rainfall-use efficiencies."[3]

Farmers are guided by experience of an undependable environment characterized by erratic rainfall which frequently occurs in high intensities. Therefore, new soil- and water-management and conservation technology must be associated with immediate and clearly visible impacts on the levels and stability of agricultural production. Long-term or small gains will not capture the imagination of farmers, and will impede acceptance.

Research on land and water management at ICRISAT aims to fulfill two primary objectives:

[3] "Rainfall-use efficiency" is defined as the agricultural production (kg or money) in relation to annual precipitation (cm), it is the product of effective rainfall- and water-use efficiency

1. To assist in identification of criteria for new varieties, cropping systems, and crop-management technologies which increase long-term rainfall-use efficiency while contributing to runoff control and erosion protection.

2. To develop improved resource-management technology, which more-effectively conserves and utilizes the rainfall and the soil to support crop-production systems which maintain productivity and assure dependable harvests.

### The Effects of Present Land and Water Conservation Practices

In India, presently accepted soil- and water-conservation practices consist largely of bunding. The methodology used for determining the moisture-conservation effects of contour bunding on crop production has been to evaluate the trend of the yields in relation to the distance from contour bunds. Crop-yield samples representative of seepage areas, borrow-pit areas, areas where water is impounded, transition areas, and the areas beyond the zone where water is impounded, were collected. The latter presumably do not benefit from a moisture-conservation effect (Fig 34a).

On a total-watershed basis (BW6), the average area occupied by contour bunds was 2.3 percent, while the average area submerged above the bunds amounted to 6.1 percent. The effects of several contour bunds on rainy-season crop yields have been summarized (Fig 34b). Crop yields increased with distance away from the bunds; yields in the area affected by seepage and impounded water were from 37 to 53 percent (pearl millet) and from 40 to 45 percent (maize) less than the yields measured from areas not affected by bunds. The overall reduction in yield levels (including the effects of the area occupied by the bunds) was 8 to 10 percent

*Figure 33. Bullock-drawn planter sowing millet and pigeonpea intercrop.*

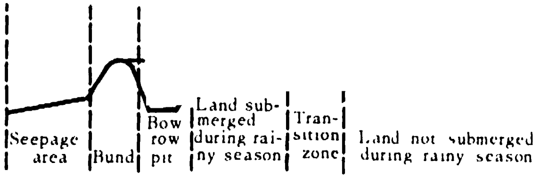



**Figure 34a. Cross section of typical contour-bunded area.**

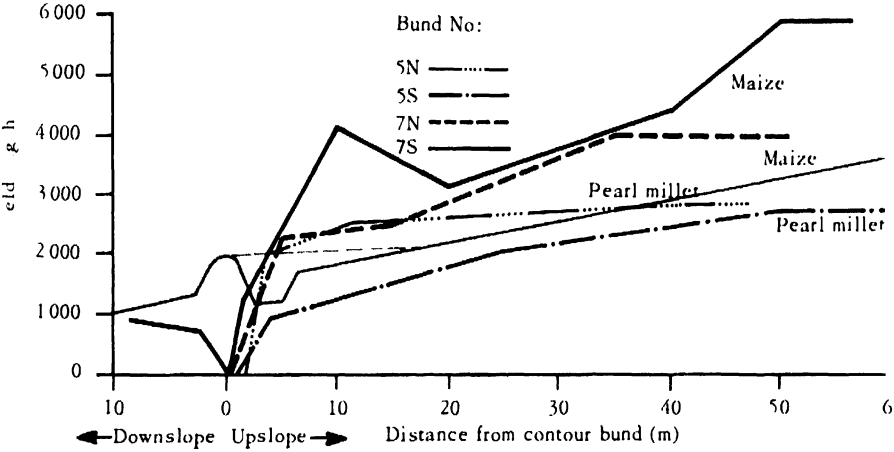



**Figure 34b. Effect of contour bunding on rainy season crops of maize and pearl millet growing on black soil.**

for pearl millet and 5 to 6 percent for maize; the submerged land area in pearl millet fields was higher (14%) than in maize fields (5.5%). Yield levels were higher on the north side of the watershed, due to a higher fertility level applied on this area.

The effects of contour bunding on crop ields in post-rainy season 1975 have been ummarized (Fig 34c, 34d). Yields were everely reduced in the areas where water was mpounded during the rainy season (Fig 35); igeonpea yields were reduced by 41 to 51 percent and safflower yields by 19 to 43 percent. 'ields of chickpea in the borrow-pit areas xceeded those in the remaining zone in which ater was impounded, possibly due to sediment deposition; the yield reduction in the latter zone was between 4 and 36 percent. The overall yield reduction for pigeonpea amounted to 4 to 5 percent, for safflower 3 to 5 percent, and for chickpea 2 to 5 percent. As expected, the adverse effects of contour bunding on crop production due to inadequate drainage is less expressed during the post-rainy season (Fig 34e).

In conclusion, well-designed and maintained contour bunds on black soils undoubtedly conserve soil and for this purpose contour bunds are perhaps efficient. However, it appears that the associated disadvantages—mainly water stagnation and the absence of crop drainage (particularly during the rainy season) and occasional breaching of bunds and the resulting channelized flow of water causing concentrated erosion—outweigh any advantage from the standpoint of soil conservation.

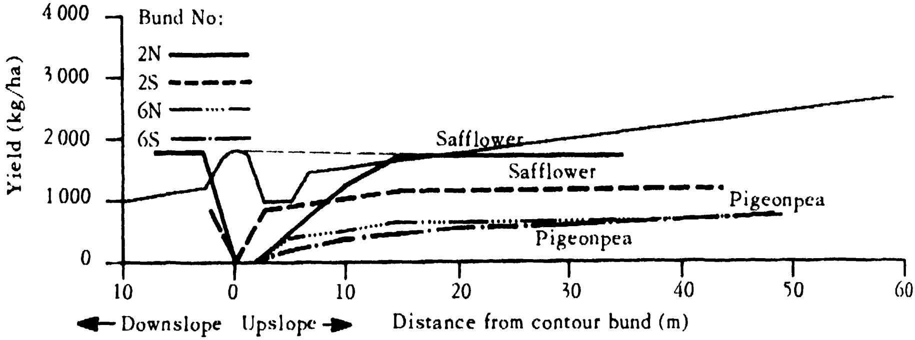



**Figure 34c. Effect of contour bunding on post-rainy season crops of safflower and pigeonpea growing on black soil.**

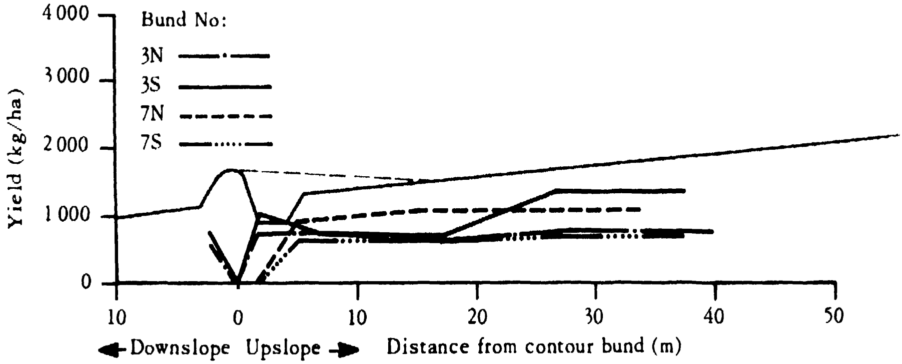



**Figure 34d. Effect of contour bunding on post-rainy season chickpea growing on black soil.**

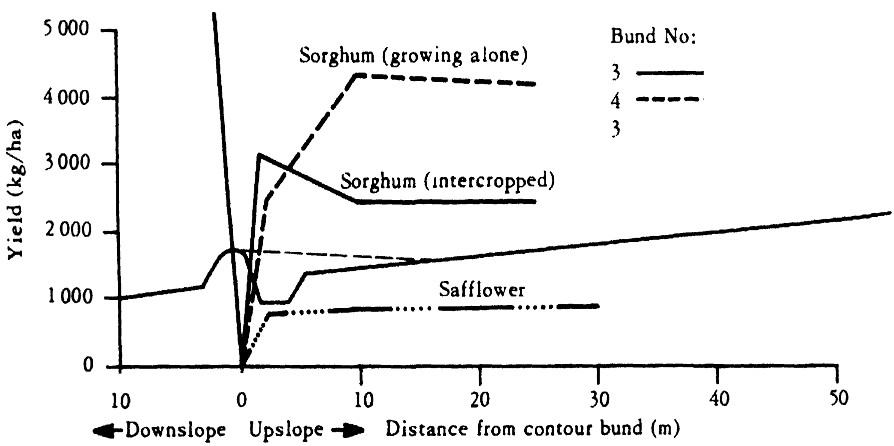



**Figure 34e. Effect of contour bunding on intercropped sorghum growing on red soil during the rainy season, sorghum growing alone, and safflower growing during the post-rainy season.**

*Figure 35. Poor chickpea growth due to stagnant water above contour bund on BW6 B.*

### Ridged and Flat Planting

Appropriate practices for the management and conservation of land and water resources will vary according to different agroclimatic and soil environments. However, similar principles may apply across large regions. Graded ridges and furrows appear to have considerable potential in soil and water management and in conservation. Ridges fulfill one essential requirement of farming systems for the SAT; water is managed and controlled at the place where it occurs as rainfall.

One experiment conducted during 1975 and 1976 attempted to critically evaluate soil- and water-management aspects of different systems of land cultivation and planting on deep black, shallow black, and red soils. Field-scale plots ranging from 0.3 to 0.4 ha were used as eplicates. Large plots are essential for this type of research, because the relevant factors unoff, erosion, and drainage) do not express iemselves on small plots. Surface runoff and oil erosion were measured for one replicate of ich of the treatments. Soil moisture was monored on all plots. Visual observations of rainage and weed conditions were recorded uring the rainy season; the weed count was ibstantially less in the ridge than in the flat ianting.

On red soils (RW2 C), three cultivation treatments were compared. They were a narrow-ridged system with furrows at 75 cm, a broad-ridged system with furrows at 150 cm, and flat planting, all at average slopes of .04 percent. Broad ridges were included because ''slaking'' of narrow ridges was experienced in rainy season 1973 and rainy season 1974 and also because of problems encountered in planting an intercrop on narrow ridges. With rainfall well distributed during rainy season 1975, significant yield differences were not observed between treatments (Table 56).

The plots planted to a narrow ridge-and-furrow system produced the greatest amount of runoff and the erosion measured from this treatment also exceeded that observed from the other two treatments. The runoff observed from broad ridges was relatively small, and soil losses from this treatment appeared to be within the acceptable range. It is probable that the 75-cm ridge-and-furrow treatment will be eliminated in further studies on red soils as this treatment does not appear suitable on soils of this type.

After a year's experimentation, it seems premature to draw conclusions, particularly since rainy season 1975 was characterized by unusually wet conditions throughout. Several aspects of ridged cultivation on red and black soils need to be further investigated. The broad-ridged system will be included in experimentation on black soils. Land-management and moisture-conservation methods must be better-tailored to the specific requirements of crops in order to derive a viable system of farming. The technique of experimentation needs considerable improvement and refinement; when large plots are used, soil or fertility differences should not play a significant role. Entire-plot yields rather than random samples should be taken as the measure of performance of a given practice.

### Optimum Use of Supplemental Water

Surface and groundwater resources could potentially be used to decrease the disturbing effect of erratic rainfall; supplemental water is

Table 56. **Runoff, erosion, and yields of three land-management treatments in red-soil watershed RW2 C.**

| Treatment | Runoff | Erosion | Sorghum yield | |
|---|---|---|---|---|
| | | | regular | ratoon |
| | (mm/ha) | (metric ton/ha) | (kg/ha) | (kg/ha) |
| Narrow ridges (75-cm) | 235 | 3.68 | 2910 | 5100 |
| Flat planting | 181 | 1.73 | 3390 | 5600 |
| Broad ridges (150-cm) | 166 | 1.85 | 3220 | 5900 |

limited and should therefore be used with utmost efficiency. In irrigation research at ICRISAT Center, supplemental water is considered to be a back-up resource to stabilize rainfed agriculture. The investigations are aimed at developing a methodology which makes it feasible to use supplemental water as "life-saving" irrigation during the rainy season and to extend the growing season into the dry post-rainy period.

Supplemental-water experiments were conducted on deep black soil (BT3) and red soil (RW1). Irrigation water was applied in alternate rows to all supplemental-water treatments to increase the application efficiency. Treatments during rainy season 1975 on black soils and on the red soil consisted of:

(1) No supplemental irrigation;

(2) One supplemental irrigation of 25 mm immediately after signs of wilting were clearly observed during 3 (2) hours of the day;[1]

(3) A supplemental irrigation of 25 mm immediately after signs of wilting were clearly observed during 7 (5) hours of the day;[1]

[1]The shorter wilting-duration criterion (given in parenthesis) was used when the crops were in the reproductive stage.

(4) Two supplemental irrigations of 25 mm each when and if the conditions described under 2 occurred twice during the season;

(5) Two supplemental irrigations of 25 mm each when and if the conditions described under 3 occurred twice during the season;

(6) A control treatment; water supplied when 50 percent of the available water had been used by the crop.

Due to the cracking nature of black soils, different treatments were applied during the post-rainy season 1975; they consisted of:

(1) No supplemental irrigation;

(2) A 25-mm supplemental-water application immediately after sufficient moisture-holding capacity had become available;

(3) A 50-mm supplemental-water application immediately after sufficient moisture-holding capacity had become available;

(4) A 25-mm supplemental-water application after an initial 25-mm supplemental-water application was depleted;

(5) A 50-mm supplemental-water application

after an initial 50-mm supplemental-water application was depleted;

(6) A control treatment; water supplied when 50 percent of the available water had been used.

No responses to irrigation treatments were obtained during the rainy season 1975 due to well distributed rainfall. In the post-rainy season, two 25-mm irrigations to tomato on red soil resulted in a yield of 23.4 metric ton/ha as compared to 12.5 metric ton/ha in the no-irrigation treatment. The monetary value of the yield gain due to irrigation of tomato can be conservatively estimated at Rs 3 300/ha or at Rs 660/ha-cm of water (the average price received during the 1975 season was Rs 63/100 kg which would be equivalent to Rs 1 370/ha-cm). Only one irrigation was given to safflower (at the 7 hours of observed wilting stage); this treatment resulted in a yield of 1.38 metric ton/ha compared to 1.04 metric ton/ha in the no-irrigation treatment or 130 kg/ha-cm of water.

Yields obtained in the post-rainy season on black soils have been summarized in Table 57. Maize was found to be extremely sensitive to moisture stress; even though the season started with an average of 200 mm of available moisture in the soil, maize yields were almost zero without irrigation. Two applications of 25 mm each resulted in a grain yield of only 720 kg/ha while full irrigation (consisting of four applications of 100 mm) resulted in a grain yield of 2 120 kg/ha. A 3 490-kg/ha yield of sorghum was obtained when two irrigations of 50 mm were given, compared to 1 710 kg/ha without irrigation; this yield gain of 440 kg/ha-cm of

**Table 57. Effect of irrigation treatment upon the grain or pod and fodder yields of four crops on black soil during the post-rainy season.**

| Treatment No | Water applied | Sun-flower | Ground-nuts | Maize | | Sorghum | |
|---|---|---|---|---|---|---|---|
| | | | | Grain | Fodder | Grain | Fodder |
| | (mm) | (kg/ha) | (kg/ha) | (kg/ha) | (metric ton/ha) | (kg/ha) | (metric ton/ha) |
| 1 | None | 420 | 370 | 85 | 5.47 | 1 710 | 4.66 |
| 2 | 25[a] | 930 | 550 | 420 | 8.72 | 2 260 | 5.68 |
| 3 | 25[a] | 990 | 630 | 410 | 9.67 | 2 850 | 6.18 |
| 4 | 25 + 25[b] | 890 | 630 | 400 | 9.01 | 2 740 | 6.58 |
| 5 | 25 + 25[b] | 980 | 770 | 720 | 11.68 | 3 490 | 8.47 |
| 6 | Normal | 1 120 | 3 333 | 2 120 | 18.47 | 3 800 | 11.35 |
| | F value | 16.714 | 53.13 | 25.80 | 42.46 | 25.35 | 10.50 |
| | LSD (.05) | 176 | — | 430 | 2.027 | 519 | 2.233 |

[a] First irrigation on treatments 2 and 3 between 28 Nov and 3 Dec 1975.

[b] Second irrigation on treatments 4 and 5 on 10 Jan 1976.

supplemental water has a value of Rs 330/ha-cm. Fodder yields also were significantly increased. Sunflower yields were increased from 420 kg/ha without irrigation to 990 kg with a 25-mm supplemental-water application. This resulted in a monetary increase of Rs 342/ha-cm. Groundnut yields were very unsatisfactory; pegs were not penetrating into the soil due to surface hardness.

### Looking Ahead in Land and Water Management

Research initiated during the past few years will be continued and improved to provide conclusive evidence. Considerably more attention will be paid to participation in cooperative research on hydrology and improved resource management at a number of locations in the Indian SAT and also in West Africa (see Cooperative Research). It is anticipated that training of research and agricultural development personnel will become a more important responsibility.

## Agronomy

To capitalize on an improved soil-and water-resource base, it is essential to develop cropping systems which will provide a continuum of productive crop growth from the onset of rain to as far as possible into the post-rainy season. Considerable research has been conducted on the agronomy of individual crops; however, information on inter-species competition and weed management when two or more crops are grown in intercropping or relay-cropping systems is lacking.

Farmers in the SAT grow most of their crops in various crop mixtures at low levels of technology. Recent research indicates that, at higher levels of technology, intercropping systems are superior to sole cropping in terms of production potential. To exploit this, basic information on competition between crops for light, moisture, and nutrients and on methods of soil and crop management that will minimize weed, insect, and disease problems should be developed. Thus, the main thrust of the agronomic research program is the development of economically viable cropping systems and management systems that will make optimum use of any given environment.

The scope of the agronomic research during the past season involved a wide range of areas, including—

—Intercropping investigations

—Relay and sequential crop studies

—Genotype evaluation trials

—Weed-management systems, and

—Steps toward improved technology.

### Intercropping Investigations

Intercropping or mixed cropping evolved through the centuries in traditional agriculture in tropical or sub-tropical regions, and today is widely practiced in the SAT, where most crops are still harvested by hand. Even though mixed cropping is centuries old, the modern concepts of intercropping are relatively new. Since water is the most limiting natural resource in agricultural production in the rainfed SAT, the major thrust in the development of improved cropping systems is to optimize the utilization of the rainfall.

Intercropping provides the surest means of producing two or more crops, thereby making efficient use of the seasonal rainfall. The basic concept of intercropping is that two or more species intercropped can exploit the environment better than either of the species grown separately. Crop species and genotypes grown in the SAT represent a wide range of plant heights, sizes, shapes, rates of establishment, duration of growth, and so forth. The cropping-systems program at ICRISAT aims to develop principles related to the various plant characters that will provide guidelines in determining the best combinations of crop types and plant populations to utilize any given environment on a time- and space-sharing basis (Fig 36).

A study involving two base crops (pigeonpea and sorghum) and six intercrops (pearl millet Setaria, sorghum, soybean, cowpea, and

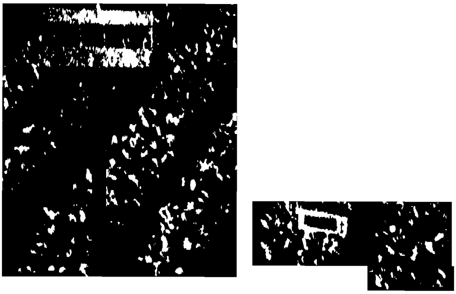


Figure 36. Three-crop intercropping experiment.

pigeonpea) was established in rainy season 1975 to study the effect of light and moisture competition between different crop types.

Data in Table 58 illustrate the two intercropping combinations that were relatively noncompetitive and tended to use the environment most effectively. These data indicate that the most favorable intercropping combination is a spreading slow-establishing pigeonpea of 6 months' duration with a rapid-establishing early maturing and upright nonratooning cereal crop, such as Setaria or pearl millet. Setaria produced 3.3 metric tons/ha, either as an intercrop with pigeonpea or as a pure crop. Likewise, pigeonpea produced 2.5 metric tons/ha either as a pure crop or with the Setaria intercrop on black soil (Table 58). Thus the intercrop combination of these two plant types produced about double the yield of the shared-crop system in which each crop was grown as a pure crop on one-half of the plot. In the pearl millet-pigeonpea intercropping system, pigeonpea had no depressing effect upon the pearl millet. Although the pearl millet depressed pigeonpea yield somewhat, the yield of the intercrop combination was 83 percent greater than that of the pure crops in a shared-crop system.

An experiment was conducted to evaluate two spreading and two compact pigeonpea genotypes at 75-cm and 150-cm row spacings, with and without a sorghum intercrop (Fig. 37). The yield of ST1, a spreading 180-day maturity genotype, was significantly higher than that of any of the other three cultivars on either soil. There was no difference in yield between the 75-cm row spacing and the 150-cm row spacing in ST1, indicating the ability of this spreading cultivar to adequately utilize the wider row spacing. The compact type (Hy 3A) did not show this ability and thus the yield of the 150-cm row spacing was reduced. The ability of the spreading type to utilize the 150-cm row spacing late in the season allows more space for intercrops to utilize the environment early in the season, thus increasing the potential for total production of the intercropping system.

The next best way of providing a continuum of crop growth throughout the rainy and post-rainy seasons is by ratoon cropping. Studies are underway to identify genotypes of several crop species which have the ability to regrow and produce two successful grain crops. However, data are not yet conclusive.

*Figure 37. Pigeonpea at 75- and at 150-cm row spacings with and without sorghum intercrop.*

### Relay and Sequential Crop Studies

Relay and sequential cropping also provide a potential means of double cropping. A comprehensive experiment was conducted to compare the sensitivity of four post-rainy season crops to light and moisture competition (Fig 38). These four crops were planted in the following three rainy season 1975 situations:

1. Monsoon—fallow
2. Partial shade (every second maize plant harvested for greencobs and fodder 24 days before grain harvest).

**Table 58. Grain yield of crops growing alone compared with growing in an intercropping system on a black soil.**

| | Pigeonpea crop alone | Pigeonpea + Setaria intercrop | Setaria crop alone |
|---|---|---|---|
| | (kg/ha) | (kg/ha) | (kg/ha) |
| Pigeonpea | 2 530 | 2 530 | |
| Setaria | — | 3 330 | 3 290 |
| | **Pigeonpea crop alone** | **Pigeonpea + pearl millet intercrop** | **Pearl millet crop alone** |
| | (kg/ha) | (kg/ha) | kg/ha |
| Pigeonpea | 2 530 | 1 970 | — |
| Pearl millet | — | 3 390 | 3 090 |

*Figure 38. Relay-planted safflower growing in rainy season maize.*

3. Full shade (all maize plants allowed to grow until physiological maturity).

In the partial-shade treatment, 24 500 green-cobs/ha were removed at the roasting-ear stage and the remaining 50 percent of the plants produced 3 790 kg/ha of grain (Fig 39). In the full-shade treatment, maize yield was 7 340 kg/ha. Data in Figure 39 indicate that the gross monetary value for double-cropping (rainy + post-rainy) was three- to four-fold the single (post-rainy) cropping. There were slight differential responses to shading, with sorghum exhibiting the greatest yield reduction due to light competition and safflower and groundnut the least (Fig 38).

### Genotype-evaluation Trials

Genotype-evaluation trials were conducted on the following crops during rainy season 1975: black gram (*Phaseolus mungo*), cowpea (*Vigna sinesis*), mungbean (*Phaseolus aureus*), soybean (*Glycine max*), groundnut (*Arachis hypogaea*), and sesame (*Sesamum indicum*). Castor bean (*Ricinus communis*), safflower (*Carthamus tinctorius*), and wheat (*Triticum aestivum*), were evaluated in post-rainy season 1975.

After 2 years of evaluation, several promising genotypes were identified in various crops and these are being further tested in intercropping and relay-cropping systems.

### Weed-management Systems

The ultimate objective and scope of weed research at ICRISAT is to develop effective and economically viable weed-management systems for agriculture in the SAT. Initially, emphasis is being given to alternative weed-management systems for ICRISAT's major

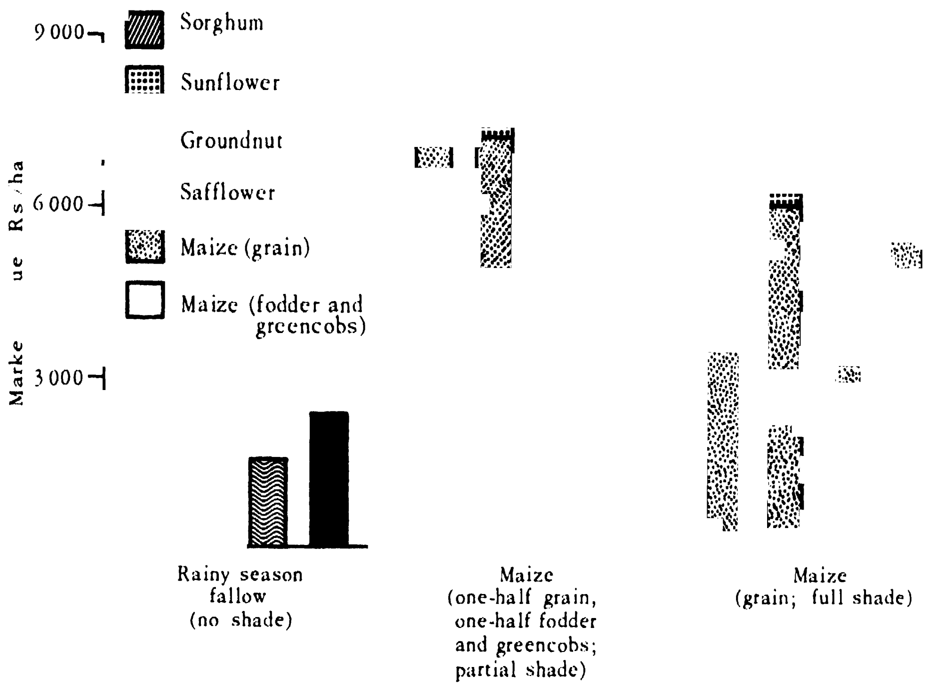



**Figure 39. Effect of maize harvest method and rainy season fallow upon monetary value of the rainy season crop plus the relay crops. In maize harvested for greencobs, every other row was taken. Maize greencobs brought Rs 2 per dozen ears at harvest; maize grain sold for Rs 80 per 100 kg. Rs 200 were received for each 100 kg of groundnut; sunflower and safflower brought Rs 150 per 100 kg; and sorghum sold for Rs 75 per 100 kg.**

crops (sorghum, millet, pigeonpea, chickpea, and groundnut) and for important cropping systems. Since farmers of the SAT have limited resources, an integrated approach to weed management is being investigated; physical, cultural, biological, ecological, and chemical methods of weed management are employed. A long-range objective is to manipulate weeds and shift the crop-weed balance in favor of crops through a combination of traditional and modern control methods.

In 1975, the first year of the weed-management research program, numerous small trials were initiated on several important SAT crops to study methods and timing of weed control. Groundnuts were found to be highly susceptible to weed competition. In a trial on red soil, the unweeded check produced only 620 kg/ha compared to 2 140 kg/ha on the weed-free (herbicide-treated) plot. In the case of sorghum and millets the yield reduction in the unweeded plot was about 70 percent. The data (Fig 40) emphasize the importance of early weed control in sorghum, pearl millet, and groundnut.

Weed ecology or habitat management in the SAT will receive major emphasis. Investigations on weed ecology were initiated by monitoring 5- by 5-m areas in different soil-, water-, and crop-management systems on the operational watershed units to determine trends in weed infestation and possible "shifts" in the various systems.

Weed-yield determinations in the intercrop experiment (Fig 37) indicate far greater weed

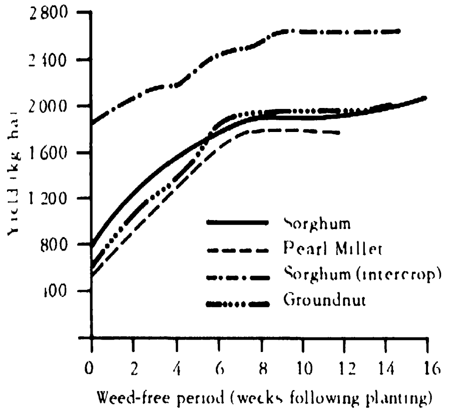



**Figure 40. Critical period of crop-weed competition during the rainy season.**

yields in sole-crop pigeonpea compared to intercropping with sorghum. Thus, the intercropping system increases total crop production and decreases the cost of weed management.

Preliminary measurements of weed-root size, depth, and density were made and a preliminary classification of weed roots developed. This type of study will be continued in order to better understand the competition for nutrients and moisture by various weed types.

## Steps Toward Improved Technology

In the development and implementation of any new or improved technology there are many facets or steps involved. If one considered each of the individual facets, the total number would be unmanageably large. For convenience the many facets were grouped into the following four phases: variety, fertilization, soil and crop management, and water management.

In this experiment, comparisons were made between local and improved technology, as defined in Table 59. There was a small increase for the extra 50 kg of nitrogen per hectare; but the treatment × nitrogen interaction was not significant. Thus, treatment yields given are means of the two nitrogen levels. The data (Table 59) indicate the following:

1. With local fertilization and local soil- and crop-management practices, there was no yield difference between the local (PJ8K) and the improved (CSH5) cultivar.

2. With improved fertilization, yields of both cultivars were increased significantly; however, by far the greatest improvement in the yield occurred when improved fertilization and improved soil and crop management practices were *combined* with the improved cultivar.

## Looking Ahead in Steps Toward Improved Technology

The addition of a cropping-systems agronomist has enabled an expansion of the intercropping and other cropping-systems research.

The weed-management research program is being expanded to include screening of a wide range of germplasm of the five ICRISAT crops for competitiveness with weeds and tolerance to herbicides. Other new activities include weed-management research in various types of cropping systems, survey of weeds and weeding systems in the SAT, and studies of minimum tillage and residual effects of herbicides.

The genotype-evaluation program started in 1974 and continued through the 1975 season will be phased out, as such, in 1976. The last intensive program of testing promising cultivars of several crops under intercropping conditions is being initiated on the red and on the black soils.

In cooperation with the breeding programs, 50 pigeonpea genotypes are being tested under intercropping conditions in the red- and the black-soil watersheds and 40 pearl millet genotypes are being tested under various intercrop and plant-population conditions.

The improved-technology experiment is being continued in red soils; a similar experiment involving pigeonpea and maize intercrop is being conducted in medium-depth black soils.

**Table 59. Effect of various steps toward technology (local vs improved) upon sorghum-grain yields on a red soil**

| Treat No | Variety | Fertilization[a] | Soil, crop[b] management | Grain yield | Increase over local fertilization, management |
|---|---|---|---|---|---|
| | | | | (kg/ha) | (kg/ha) |
| 1 | Local | Local | Local | 1 190 | — |
| 2 | Local | Improved | Local | 1 770 | 580 |
| 3 | Local | Improved | Improved | 2 240 | 1 050 |
| 4 | CSH-5 | Local | Local | 1 010 | — |
| 5 | CSH-5 | Improved | Local | 2 390 | 1 380 |
| 6 | CSH-5 | Improved | Improved | 3 480 | 2 470 |
| LSD (.05) | | | | 540 | |
| Subplot (N rate). | | | | | |
| a 50-25-0 | | | | 1 830 | — |
| b. 100-25-0 | | | | 2 190 | 360 |
| LSD (.05) | | | | 270 | |

a. Treatments 1 and 4 - 50 cartloads or 15 metric tons/ha FYM (farmyard manure) Treatments 2, 3, 5 and 6 - 125 kg/ha of 18-46-0 applied at planting
Subplot "a" received 28 kg/ha of N side-dressed and subplot "b" 78 kg/ha of N side-dressed

b. "Local" soil and crop management = Land preparation with desi implements, fertilizers broadcast and seed planted with three-row desi drill, 30 cm between rows

"Improved" soil and crop management = All tillage, planting, and cultivation with improved bullock-drawn implements Seed planted and fertilizer banded in rows 75 cm apart on 150-cm broad ridges No water applied during rainy season, therefore the water-management treatments were combined with treatments 3 and 6

## Cropping Entomology

Considerable progress was made in investigation of the bionomics of important pest species at ICRISAT Center, and particularly of the gram pod borer, *Heliothis armigera* (Hubner). In addition, parasites of pest species occurring on a range of crops were recorded.

Experimental work on pests occurring in intercrop situations and various crop proportions was expanded.

**Heliothidinae Complex**

Collection of larvae from crops and weeds confirmed that the three species of Heliothidinae at ICRISAT Center are *Heliothis armigera*

(Hubner), *H. peltigera* Schiff. and *H. assulta* Guenee; the former is dominant on crops grown at the Center. *H. armigera* was recorded from 50 cultivated and 17 weed species (Table 60). Subspeciation within *H. armigera* damaging crop hosts was not detected. Detailed study of male genitalia of individuals reared on natural hosts or bred on a single food-plant for three generations from a single male and a single female originating from the particular host plant revealed that the number of stout spines on their aedeagal cornuti varied from 10 to 15 (Table 61). This character is, therefore, not a reliable taxonomic aid.

Mating behavior was studied in the laboratory and it is clear that scars caused by the cornutal spines of males on the inner walls of the appendix bursae of females will serve as an accurate criterion to separate mated and virgin females in the trap catch. The presence of sperm/spermatophores in the fundus bursae will provide confirmatory evidence.

Study of the *H. armigera* life cycle revealed that seven to eight overlapping generations are found in a year. A minute proportion (0.3%) of the larval population entered into pupal diapause in 1974-1975; the majority of the pupae were female and emerged in June. Some

**Table 60. Recorded hosts of pod borer, *Heliothis armigera* (Hubner) at ICRISAT Center, 1974-1976.**

| Class | Host name |
|---|---|
| Cereals | Sorghum, pearl millet, maize, wheat, triticale, Setaria, Eleusine millet. |
| Pulses & legumes | Pigeonpea, chickpea, mungbean, black gram, soybean, field bean, cowpea, horse gram, wingbean. |
| Vegetable and root crops | *Hibiscus esculentus*, tomato, chilli, eggplant, cauliflower, cabbage, onion, potato, spinach, sweet potato. |
| Oil and fiber plants | Castor, cotton, peanut, sesamum, safflower, sunflower, sunnhemp. |
| Woody and fruit trees | Mango, banana, *Citrus* sp., *Eucalyptus* sp., *Acacia* sp. |
| Garden and ornamental plants | Rose, garden pea, marigold, chrysanthemum, pansy, phlox, cosmos, *Antirrhinium*, *Hibiscus rosasinensis*, *Ocimum* sp. |
| Stimulants and narcotics | Tobacco |
| Weeds | *Datura metal*, *Acanthospermum hispidum*, *Amaranthus viridis*, *Sonchus arvensis*, *Lantana camara*, *Vernonia cinerea*, *Tephrosia purpurea*, *Asteracantha longifolia*, *Hibiscus panduraeformis*, *Crotolaria retusa*, *Trichodesma indicum*, *Eclipta alba*, *Phyllanthus* sp., *Martynia annuva*, *Trianthema* sp., *Tridax procumbens*, and an unidentified post-rainy season Euphorbiacious weed. |

larvae entered into prolonged pupal periods (35 to 85 days) in 1975-1976, but all emerged during the January-March period. These larvae, except for one, were obtained from pulses.

Three peaks of *H. armigera* activity were recorded at light in 1974-1975. The first peak (mid-Sep) was associated with high levels of oviposition on pigeonpea/sunflower, the second (mid-Nov) with oviposition on chickpea, and the third (Mar-Apr) with particularly extensive oviposition on tomato/maize. The first peak was displaced by about 2 and the second by 3 weeks compared with 1974 (Fig 41). More females than males were taken at light over the year; all moths caught in June were females. In view of the observations on diapausing pupae, this ratio may be of significance The maximum numbers (nearly 50% of the total catch) were trapped during April 1975 and minimum (less than 1%) in June 1975 Numbers were affected by lunar cycles and were lowest when the moon was full. Both virgin and fertile females were trapped at light

Detailed field observations revealed that the peak of oviposition of *H. armigera* on pigeonpea was related to maximum flower production and occurred 8 to 10 days after full moon in November (on cv Hy-2) and in January (on cv ICRISAT-1) in black soils and 2 days prior to full moon in October (on ICRISAT-1) in red soils. On irrigated pearl millet, maximum oviposition was observed on the day of full moon in mid-April.

Information on peaks of *Heliothis* obtained from traps and from egg and larval counts in the field during the past several seasons is enabling

**Table 61. Number of cornutal spines on *Heliothis armigera* (Hubner) at ICRISAT Center, 1975-1976.**

| Number of spines | Sorghum B[a] | Sorghum R[a] | Pigeonpea B | Pigeonpea R | Chickpea B | Chickpea R | Trapped at Light (March) |
|---|---|---|---|---|---|---|---|
| | (number of moths)[b] | | | | | | |
| 10 | 0 | 0 | 1 | 4 | 1 | 0 | 0 |
| 11 | 2 | 1 | 9 | 9 | 5 | 4 | 5 |
| 12 | 10 | 13 | 9 | 5 | 13 | 14 | 12 |
| 13 | 10 | 9 | 2 | 5 | 3 | 6 | 7 |
| 14 | 3 | 1 | 4 | 2 | 3 | 1 | 1 |
| 15 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Range (spines) | 11-14 | 11-15 | 10-14 | 10-14 | 10-14 | 11-14 | 11-14 |
| Mean | 12.56 | 12.52 | 11.96 | 11.68 | 12.08 | 12.16 | 12.16 |

[a] B = bred for three generations from parents originally collected from named crop, R – obtained from larvae collected from named crop

[b] Based on 25 males

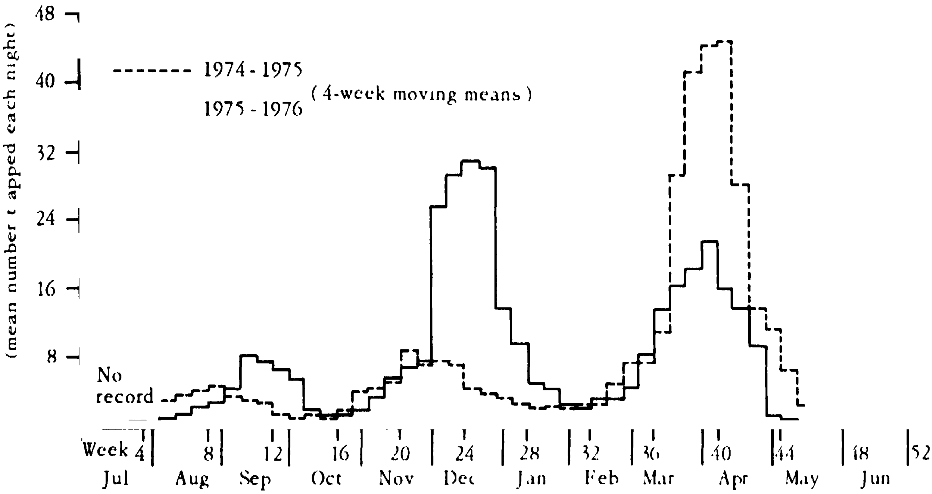



**Figure 41. Catch of *Heliothis armigera* (Hubner) at light trap No. 1, ICRISAT Center, 1974-1975 and 1975-1976.**

us to gain valuable insight into best dates for screening, escaping damage, timing of pest-control measures, and parasitism on crops—particularly on pulses.

Field surveys indicated that *H. armigera* was present on one crop or another in every month of the year. Any host plant flowering in summer season was a source of carry-over, and larvae could survive in low numbers on crops such as irrigated tomato, maize, pearl millet, peanut, chili, vegetables, and weeds such as *Datura metal*.

To date some 11 larval parasites (four Diptera, six Hymenoptera, and one Helminth) have been collected and identified from the three species of *Heliothis*. Only two, *Goniophthalmus halli* Mes. and an as yet unidentified Hymenopteran, were of major importance; they were particularly common on pigeonpea and chickpea. Egg parasites have not been found to date. The nematode parasites which attacked all *Heliothis* species were tentatively identified as a species of *Hexamermis* by the Zoological Institute, Academy of Sciences, USSR.

In addition to *H. armigera*, two other pod borers of legumes and pulses, *Etiella zinckenella* Treits. and *Adisura stigmatica* Warr., produced very-low numbers of diapausing pupae.

### Intercropping Studies

Experiments based on surveillance data from 1974-1975 intercropping studies on watersheds were initiated during rainy season 1975. Pigeonpea with legumes and cereals in alternate-row combinations were used. Suitable methods for monitoring eggs and larval numbers of *H. armigera*, as well as damage caused to pigeonpea, are under development.

On cv Hy-2 laying of eggs by *H. armigera* was not observed on terminals with tiny buds, but oviposition commenced as bud swelling set in. Maximum oviposition on intercropped pigeonpea was recorded in late November, whereas a maximum oviposition in monocrop pigeonpea occurred in early to mid-November (Table 62). Far more eggs were laid on terminals of pigeonpea in intercrop blocks at peak period than were laid at peak period in monocrop. Increased oviposition was related to the observed increase in catch of *H. armigera* at light in late November (Fig 41) and the

**Table 62.** *Heliothis armigera* **eggs (E) and larvae (L) recorded (mean numbers) per 100 terminals (distal 25 cm) in counts from unsprayed plots of intercropped pigeonpea cultivar Hy-2 at ICRISAT Center, 1975-1976.**

| Treatment[a] | | October | | | November | | | December | | January | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15 | 22 | 30 | 10 | 19 | 28 | 10 | 24 | 6 | 15 |
| | | (numbers of eggs and larvae) | | | | | | | | | |
| PP + S | E | 8.00 | 19.25 | 20.50 | 26.75 | 20.50 | 25.50 | 3.50 | 0.00 | | |
| | L | 0.25 | 1.50 | 3.00 | 9.75 | 13.25 | 21.75 | 20.50 | 1.50 | | |
| PP + S* | E | 9.00 | 24.75 | 10.75 | 29.00 | 19.00 | 28.75 | 2.75 | 0.50 | | |
| | L | 0.75 | 2.50 | 2.25 | 11.00 | 10.75 | 21.50 | 19.25 | 2.50 | | |
| PP + PM | E | 22.50 | 11.25 | 11.75 | 41.75 | 47.50 | 78.50 | 7.75 | 1.25 | 12.00 | 10.75 |
| | L | 0.25 | 0.50 | 1.75 | 10.75 | 12.00 | 32.50 | 38.50 | 4.75 | 3.00 | 8.75 |
| PP + CP | E | 37.75 | 20.25 | 12.50 | 29.50 | 15.50 | 23.75 | 2.50 | 1.50 | 5.25 | 8.00 |
| | L | 4.75 | 1.25 | 3.50 | 8.75 | 6.25 | 16.00 | 18.00 | 4.00 | 2.25 | 3.25 |
| PP + FB | E | 17.50 | 19.25 | 14.75 | 36.00 | 41.50 | 50.50 | 8.00 | 0.00 | 8.75 | 14.75 |
| | L | 0.25 | 2.75 | 3.50 | 12.25 | 12.75 | 25.00 | 35.00 | 5.00 | 3.25 | 7.50 |
| PP | E | 9.75 | 20.50 | 18.50 | 31.00 | 17.25 | 13.25 | 3.25 | 0.50 | | |
| | L | 0.50 | 0.50 | 2.50 | 10.50 | 14.25 | 21.00 | 14.50 | 3.50 | | |
| Grand mean | E | 17.41 | 19.20 | 14.79 | 32.33 | 26.87 | 36.70+ | 4.62 | 0.62 | 8.66 | 11.16 |
| | L | 1.12 | 1.50 | 2.75 | 10.50 | 11.54 | 22.96 | 24.29+ | 3.54 | 2.83 | 6.50 |
| C.D. | E | | | | | | 14.78 | | | | |
| (P< .05) | L | 2.65 | | | | | | 12.79 | | | |

[a] PP = pigeonpea; S = sorghum; S* = pigeonpea/sorghum mixed in rows; PM = pearl millet; CP = cowpea; FB = field bean; + = peaks.

increased level of flower production in intercrop combinations. There was a clear relationship between egg numbers and pigeonpea flowers (overall correlation coefficient: +0.73). Open flowers attracted ovipositing females, but moths preferred to lay more eggs in the plots containing more unopened flowers (which also carried a greater number of swollen flower buds.)

Final harvest-loss assessments (based on collection of all pods from 25 plants per treatment plot) revealed that the damage due to *H. armigera* (pods showing larger holes) was least severe (26 to 29%) on monocrop and the pigeonpea/sorghum combinations (both between lines, PP + S, and within lines, PP + S*) and most severe on the pigeonpea/pearl millet and pigeonpea/legume (cowpea or field bean) combinations (40 to 59%) (Table 63).

When hundred-pod weights were determined, it was clear that weights from the pearl millet and legume combinations were far lower than those in the monocrop or sorghum plots. Fewer healthy seeds and lower seed weights were obtained from pods of the first two treatment categories. *H. armigera* was the main source of loss.

Final yield-loss data was based on actual weights of damaged and undamaged pods and seeds, calculating the potential yields as if all pods had been undamaged. Loss in pod weight due to pest-action ranged from 12 to 14.5 percent in pigeonpea/sorghum and pigeonpea monocrop situations and to as high as 26 to 37 percent in other combinations. Corresponding values for actual seed loss were 19 to 22 percent and 40 to 56 percent, respectively.

Significantly higher yields ($P < 0.05$) were obtained in monocrop and sorghum blocks (686 to 832 kg/ha) than in legume and pearl millet blocks (112 to 353 kg/ha) (Table 64). (However, it should be noted that shoot-fly attack during this season was very heavy on sorghum and competition was not as great as it might have been.)

Few early formed pods of cv Hy-3C were retained by the plants, since heavy pod-drop was experienced in December and January, coinciding with the increased activity of *H. armigera* and *M. obtusa*. Aborted pods were collected from the ground at 24 locations within the trial (6.25 m² at the center of each individual plot). Of the 4020 pods examined, some 45 percent (range 27 to 53%) were damaged by borers, 21 percent (range 11 to 29%) by podfly, 6 percent (range 3 to 8%) by both borers and podfly, and 2.5 percent (range 1 to 4%) by hymenopteran pests, *Taraostigmodes* sp., leaving 26 percent (range 16 to 36%) of the pods undamaged. Most of the pods damaged by *Taraostigmodes* sp. and most of the undamaged pods were very young, whereas pods damaged by borers and podfly were usually well-developed.

In an experiment with cv Hy-3A on four black-soil watersheds (BW2-BW5), observations in early September revealed that leaf-tier (*E. critica*) damage to 60-day-old intercropped pigeonpea was significantly higher ($P < 0.05$) in Setaria blocks than in sorghum blocks–514 to 524 webs/100 plants observed as opposed to 344 to 374 webs/100 plants in sorghum blocks (mean of eight sites in each combination). There was no significant difference in numbers of webs in high-(80 kg N/ha) and medium- (40 kg N/ha) fertility areas

**Crop Proportion (Pigeonpea v/s Sorghum) Studies**

On the pigeonpea cultivar ICRISAT-1 sown in early July in various crop proportions with the male-sterile sorghum 2077A (1:1, 3:1, 5:1, 1:3 and 1:5), the peak oviposition was recorded in mid-October on red-soil areas (102-day-old crop) and at the end of November (133-day-old crop) on black-soil areas. Oviposition peaks again appeared to be primarily associated with maximum flower production. There was heavier oviposition on black-soil areas and in both areas oviposition was heavier on widely spaced pigeonpea. This feature was also noted in the second flower flush produced by plants on black soils. Peak larval activity was prolonged on red-soil areas (early Nov-early Dec) and was at a maximum in black-soil areas in

Table 63. Pods undamaged and damaged on intercrop pigeonpea cultivar Hy-2 planted in black soils, ICRISAT Center, 1975-1976.

| Treatment[a] | Undamaged: Complete locule | Undamaged: Incomplete locule[b] | Undamaged: Total | Damaged: Lepidoptera: Big holes | Damaged: Lepidoptera: Small holes | Damaged: Lepidoptera: Webs | Damaged: Lepidoptera: Total | Damaged: Pod fly | Damaged: Hymenoptera | Overall insect damage |
|---|---|---|---|---|---|---|---|---|---|---|
| | (percentage of pods) | | | | | | | | | |
| PP + S | 44.15 | 17.40 | 61.55 | 26.63 | 5.55 | 0.23 | 32.40 | 5.94 | 0.095 | 38.44 |
| PP + S* | 43.99 | 13.92 | 57.91 | 28.92 | 6.40 | 0.43 | 35.76 | 6.21 | 0.107 | 42.08 |
| PP + PM | 26.97 | 8.47 | 35.45 | 47.98 | 7.19 | 0.14 | 55.31 | 9.23 | 0.000 | 64.54 |
| PP + CP | 26.28 | 10.30 | 36.59 | 40.57 | 9.06 | 0.63 | 51.26 | 12.13 | 0.000 | 63.40 |
| PP + FB | 20.82 | 5.47 | 26.29 | 59.07 | 8.45 | 0.08 | 67.60 | 6.10 | 0.000 | 73.71 |
| PP | 46.25 | 13.88 | 60.14 | 29.39 | 5.91 | 0.47 | 35.77 | 3.96 | 0.115 | 39.86 |
| Grand mean | 34.74 | 11.57 | 46.32 | 38.76 | 7.09 | 0.33 | 46.35 | 7.26 | 0.053 | 53.67 |
| C.D. (P < .05) | 9.99 | 3.79 | 11.60 | 13.11 | | 0.33 | 12.46 | 3.82 | | 11.60 |

[a]See Table 62. [b]One or more locules seedless.

Table 64. Mean pod and seed weight, calculated yield, and shelling percentages from intercropped pigeonpea cultivar Hy-2 at ICRISAT Center, 1975-1976.

| Treatment[a] | Yield Pods | Yield Healthy seeds | Calculated yield | Shelling percentage |
|---|---|---|---|---|
| | (kg/110 m²) | (kg/110 m²) | (kg/ha) | (%) |
| PP + S | 15.83 | 9.15 | 832.04 | 57.75 |
| PP + S* | 13.55 | 7.56 | 686.81 | 55.67 |
| PP + PM | 8.18 | 3.88 | 352.95 | 47.20 |
| PP + CP | 3.43 | 1.47 | 133.18 | 41.52 |
| PP + FB | 3.30 | 1.24 | 112.72 | 34.77 |
| PP | 14.82 | 8.50 | 772.27 | 56.92 |
| Grand mean | 9.85 | 5.30 | 481.66 | 48.97 |
| C.D. ($P < .05$) | 2.28 | 1.60 | 145.57 | 8.68 |

[a]See Table 62.

early December. Larval numbers thus reflected the differential oviposition. Since the pod-filling stage of earlier-formed pods in red soils coincided with peak larval activity, the earlier-formed pods were more heavily attacked (15 to 30%) than were the late-formed pods (12 to 26%). In black soils, earlier-formed pods were very severely attacked (67 to 81%), since formation coincided with peak larval numbers. Later-formed pods produced by the second distinct flower flush were less severely attacked (13 to 27%).

Podfly damage was from 5 to 10 percent in red-soil areas and from 13 to 20 percent in black-soil areas in pods produced in the first flush in November. The late-formed pods produced in early December on red soils were slightly attacked (1 to 2%). In contrast, the pods of second flush in black-soil areas produced in mid-January were severely attacked by podfly (42 to 54%).

There was a clear reduction in yield in black soils, despite the fact that far more pods were produced (Table 65), and this was due to increased damage caused by *H. armigera* and podfly.

### Pest Monitoring on Sorghum in Intercropping/Crop-Proportion Trials

No differences in levels of shoot-fly (*Atherigona soccata*) attack in male-sterile sorghum (2077A) grown intercropped in pigeonpea were detected in black-soil areas, in situations of high shoot-fly incidence. Earlier-sown sorghum (3 Jul 75) had fewer deadhearts

**Table 65. Mean pod counts, crop stand, and yield of pigeonpea cv ICRISAT-I grown in different crop proportions with sorghum (male-sterile line 2077A) on red and on black soils, ICRISAT Center, 1975-1976.**

| Treatment (PP:S) | Pods produced: Red soil pickings (no/25 plants) | | | Pods produced: Black soil pickings (no/25 plants) | | | | Plant population[a] (1000/ha) Red soil | Plant population[a] Black soil | Grain yield[a] (kg/ha) Red soil | Grain yield[a] Black soil pickings | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | Total | 1 | 2 | 3 | Total | | | | 1 | 2 | Total |
| 1:1 | 1311.5 | 496.5 | 1808.0 | 1077.5 | 1678.2 | 163.2 | 2919.0 | 32.677 | 34.233 | 488.4 | 145.0 | 223.7 | 368.7 |
| 3:1 | 1818.0 | 411.5 | 2229.5 | 1284.7 | 2080.0 | 139.5 | 3504.2 | 32.322 | 33.499 | 705.5 | 102.4 | 273.7 | 376.1 |
| 1:3 | 2051.0 | 558.0 | 2609.0 | 1376.2 | 2623.2 | 240.7 | 4240.2 | 17.066 | 17.021 | 355.4 | 50.4 | 174.3 | 224.8 |
| 5:1 | 1652.0 | 339.0 | 1994.2 | 1427.2 | 1835.5 | 185.5 | 3448.2 | 32.655 | 33.755 | 575.7 | 111.4 | 269.9 | 381.3 |
| 1:5 | 3506.0 | 777.2 | 4283.0 | 1691.0 | 3667.0 | 363.0 | 5692.0 | 10.811 | 11.999 | 438.4 | 39.8 | 228.1 | 267.8 |
| Grand Mean | 2067.8 | 516.6 | 2584.9 | 1371.4 | 2376.9 | 218.4 | 3960.7 | 25.106 | 26.102 | 512.7 | 89.8 | 233.9 | 323.7 |
| C.D. (P< .05) | 749.7 | | 997.7 | | | 143.5 | | 2.744 | 1.450 | | 72.1 | | |

[a] Calculated from 225-m² plot.

caused by shoot fly (33 to 48%) than did the crop sown even a few days later—on 7 July (59 to 69%). All counts were taken one month following germination.

### Pest Species on Crops at ICRISAT Center

Pest surveillance carried out on and around ICRISAT Center afforded an unique opportunity to study the pest range on cultivated species. Detailed observations were made, particularly on cereals, pulses, and oilseed crops.

On pearl millet, the incidence of blister beetles was higher on plots in isolated and pesticide-free areas than on plots within cultivated areas and where pesticides are frequently used. Highest numbers of blister beetles were present on heads with anthers. Larvae of *H. armigera* were common (12 to 24 per 100 heads) in black-soil watersheds in August, but few (less than one larva on 100 heads) were present in isolated areas. Pearl millet in the 1975 season was subjected to more insect attack than in 1974.

On cowpea, a low level of aphid *(Aphis craccivora)* activity was recorded this year in contrast to last year, when the crop grown on black and on red soils was heavily colonized. Severe millipede attack was recorded only in unsprayed plots; millipedes and banded blister beetles, *Mylabris pustulata*, were more numerous in plots with more flowers. Pods set from the first flower flush were severely damaged by pink Tortricid larvae identified as *Cydia ptychora* Heyr., whereas Lycaenids did the most damage to pods produced during second flush.

On field beans, *H. armigera* was the most frequent of the eight pod borers recorded. Soybean lines were assessed for susceptibility to leaf miner, *Stomopteryx* sp; damage was found to range from 9 to 67 percent.

Late-planted chickpea (21 Nov 1975) on entomological blocks suffered less pod-borer damage (9 to 14%) than usual and the larval population of *H. armigera* was kept low by an unidentified hymenopteran parasite.

Regular monitoring by counts and light trapping of some important pests of the SAT (more than 50 species) is providing basic information on seasonal variation of pest species.

### Looking Ahead in Cropping Entomology

Work on the bionomics of *H. armigera* will intensify and will expand to include studies on the possibility of biological and viral control. This work will involve cooperation with other research organizations.

Entomological work on intercropping and crop-proportion trials will increase. Basic combinations of crops will be reduced; plot size on black and red soils will be increased so that real pest shifts and differential parasitism levels can be accurately monitored. Later, agronomic and spraying practices will be incorporated into experiments. This is essential for a more thorough understanding of pest problems and pest-parasite relations on target crops in the SAT. Such an understanding is necessary in planning effective integrated pest-management systems.

Hopefully, preliminary approaches to establish a light-trap grid for monitoring the insect population throughout India will mature. The potential benefit from this work is considerable, particularly if it assists in understanding migratory-insect behavior.

Monitoring and identification of the main pest species on the range of crops at ICRISAT Center will continue indefinitely, so that a ranking of the relative importance of pest species on crops can be obtained. This will be linked with work on pest carry-over on out-of-season and "off-crop" situations, as this is important in overall pest-control strategy by cultural, insecticidal, and integrated means.

# RESOURCE UTILIZATION RESEARCH

## Watershed Development and Cropping Patterns

### Research Watersheds on Black and on Red Soils

Locations of present and proposed research watersheds are shown in Figure 42. Relevant

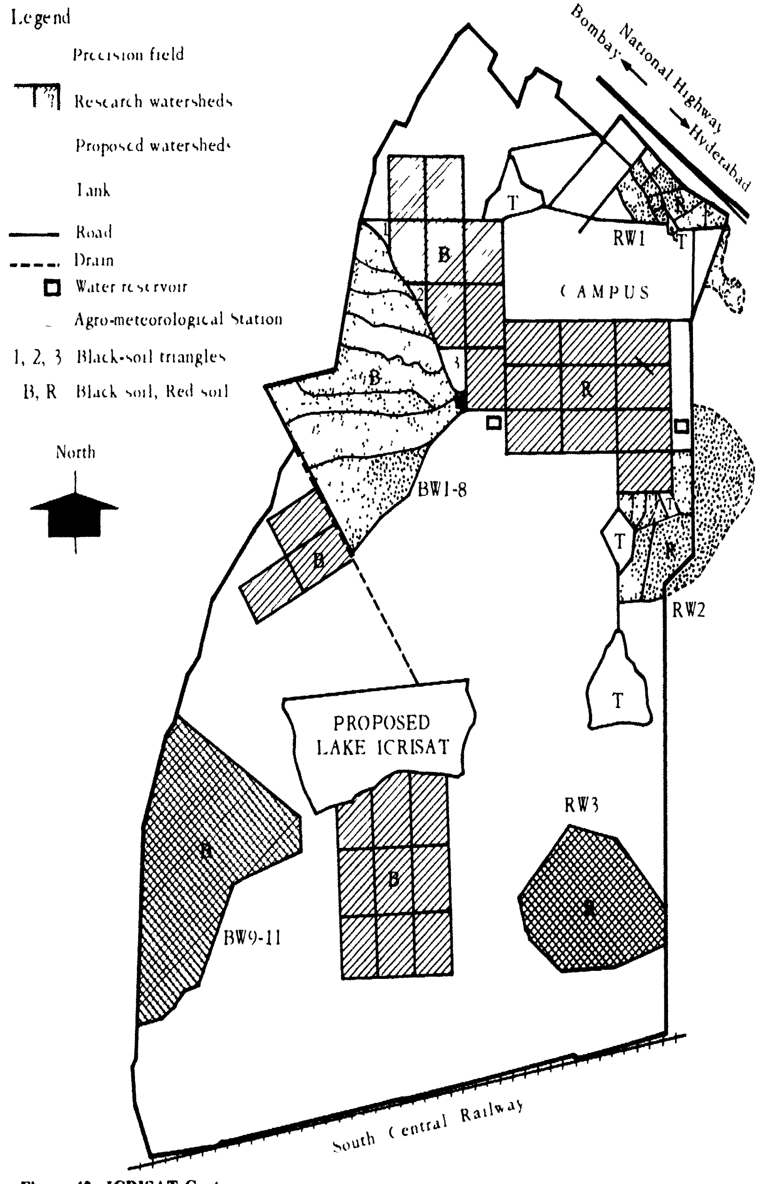



**Figure 42. ICRISAT Center.**

characteristics for each watershed unit studied during the 1975-1976 season have been summarized in Tables 66 and 67; their layout is shown in Figures 43, 44, and 45.

All watersheds except BW4 B, BW6 B, and BW8 A were double-cropped. BW4 B and BW6 B were rainy-season fallowed; and half of BW8 A was not cropped during the post-rainy season. Where double-cropping was applied, the cropping systems were (i) pigeonpea intercropped with Setaria or sorghum, (ii) pearl millet and sequential crops of sorghum or sunflower, (iii) maize and relay crops of chickpea or sunflower and (iv) sorghum and ratoon sorghum. Groundnut, rather than maize, was grown on the red soil.

**Development of a Representative Small Watershed**

When promising results are obtained from research on improved methods for the management of land and water, it becomes important to devise a development technology which can be executed within the general resource constraints to which many SAT farmers are subject. One relatively small representative watershed (BW7) was therefore developed, using exclusively resources available to the farmer and minimizing the capital requirements for development. This project provided valuable technical information and applicable data on the actual cost factors involved in resource development.

**Table 66. Land and water management and conservation features of seven red-soil watershed units.**

| Watershed | | Technology used | Planting method | Slope | Bund type | Tank-storage capacity | |
|---|---|---|---|---|---|---|---|
| No. | Area[a] | | | | | | |
| | (ha) | | | (%) | | (ha-m) | |
| RW1 C | 0.80 | Improved[b] | Flat | 0.6 | Graded | RW1 C-E | = 0.29 |
| RW1 D | 1.12 | Improved | Ridged[d] | 0.6 | - | - | |
| RW1 E | 1.02 | Improved | Flat | Contour | Contour | - | |
| RW2 A[c] | 28.90 | Grazed | - | - | - | RW2 A | = 1.2 |
| RW2 B | 2.79 | Improved | Ridged | 0.6 | Graded | RW2 B-E | = 6.0 |
| RW3 A | 10.50 | Natural | - | - | - | - | |

a In RW1, subunits A,B,E,F, and G (5.3 ha) are in agronomic experiments In RW2, subunits C (4.0 ha) and E (3.4 ha) are used for field-scale replicated experiments.

b Improved technology indicates the following:
Improved implements with animal power.
Plowing immediately after harvest to kill weeds and stubble and leaving the land rough until the rainy season starts.
Grassed waterways established.
Plant protection with minimum use of pesticides.

c The RW2 A watershed is located outside ICRISAT Center and is subjected to heavy grazing throughout the year.

d On red soils, broad ridges of 150 cm width were used.

Table 67. Land-and water-management and conservation features of 17 black-soil watershed units

| Watershed No. | Area[a] | Technology used | Planting method | Slope | Bund Type[b] | Tank-storage capacity |
|---|---|---|---|---|---|---|
| | (ha) | | | (%) | | (ha-cm) |
| Deep black soil: | | | | | | |
| BW1 | 3.41 | Improved[c] | Ridged | 0.6 | Graded | — |
| BW2 | 3.96 | Improved | Ridged | 0.6 | Field | — |
| BW3 A | 4.81 | Improved | Ridged | 0.4 | Graded | 40 |
| BW3 B | 2.55 | Improved | Ridged | 1.0 | Graded | — |
| BW4 A | 5.55 | Improved | Flat | 0.4 | Graded | — |
| BW4 B | 3.46 | Traditional[d] | Flat | — | Field | — |
| BW5 A | 7.02 | Improved | Ridged | 0.8 | Graded | 42 |
| BW6 A | 1.55 | Improved | Flat | Contour | Vertical mulch | — |
| BW6 B | 4.20 | Improved | Flat | Contour | Contour | — |
| BW7 A | 3.76 | Improved | Ridged | 0.6 | Graded | 20 |
| Medium deep to shallow black soil: | | | | | | |
| BW6 C | 4.45 | Improved | Flat | Contour | Contour | 65 |
| BW7 B | 2.72 | Improved | Ridged | 0.6 | Graded | 22.5 |
| BW7 C | 2.52 | Improved | Ridged | 0.6 | Graded | 17.5 |
| BW7 D | 4.09 | Improved | Ridged | 1.0 | Graded | 41 |
| BW7 E | 0.89 | Improved | Ridged | 0.6 | Graded | 5 |
| BW7 F | 0.69 | Improved | Ridged | 1.0 | Graded | — |
| BW8 A | 4.20 | Traditional | Flat | — | Field | — |

[a] BW5 B (8.1 ha) and BW8 B (9 0 ha) are not included; these watershed units are used for field-scale replicated experiments

[b] Graded bunds in ridged planting are low terrace-cum-channels and also serve as permanent guide terraces for the ridge-and-furrow system Bunds are standard size according to the Indian Soil Conservation specifications Field bunds are the original field-boundary bunds

[c] Improved technology indicates the following
Improved implements with animal power
Plowing immediately after harvest of the second crop to kill weeds and stubble; land preparation is completed during the hot dry season.
Grassed waterways established Plant protection by use of pesticides.
Fertilization North - 125 kg/ha 18-46-0 at planting + 58 N side-dressed
South - 125 kg/ha 18-46-0 at planting + 18 N side-dressed

[d] Traditional technology simulates local practices·
Local implements with animal power
Tillage is started after rainy season rain 'softens' the soil
Villagers' field bunds have not been removed, they remain as field boundaries.
Plant protection with minimum use of insectides.
Fertilization: Farm-yard manure at 50 cart loads/ha
Cropping: BW4 B - rainy season fallow and post-rainy season cropping
BW8 A - rainy season cropping and partly post-rainy season fallow.

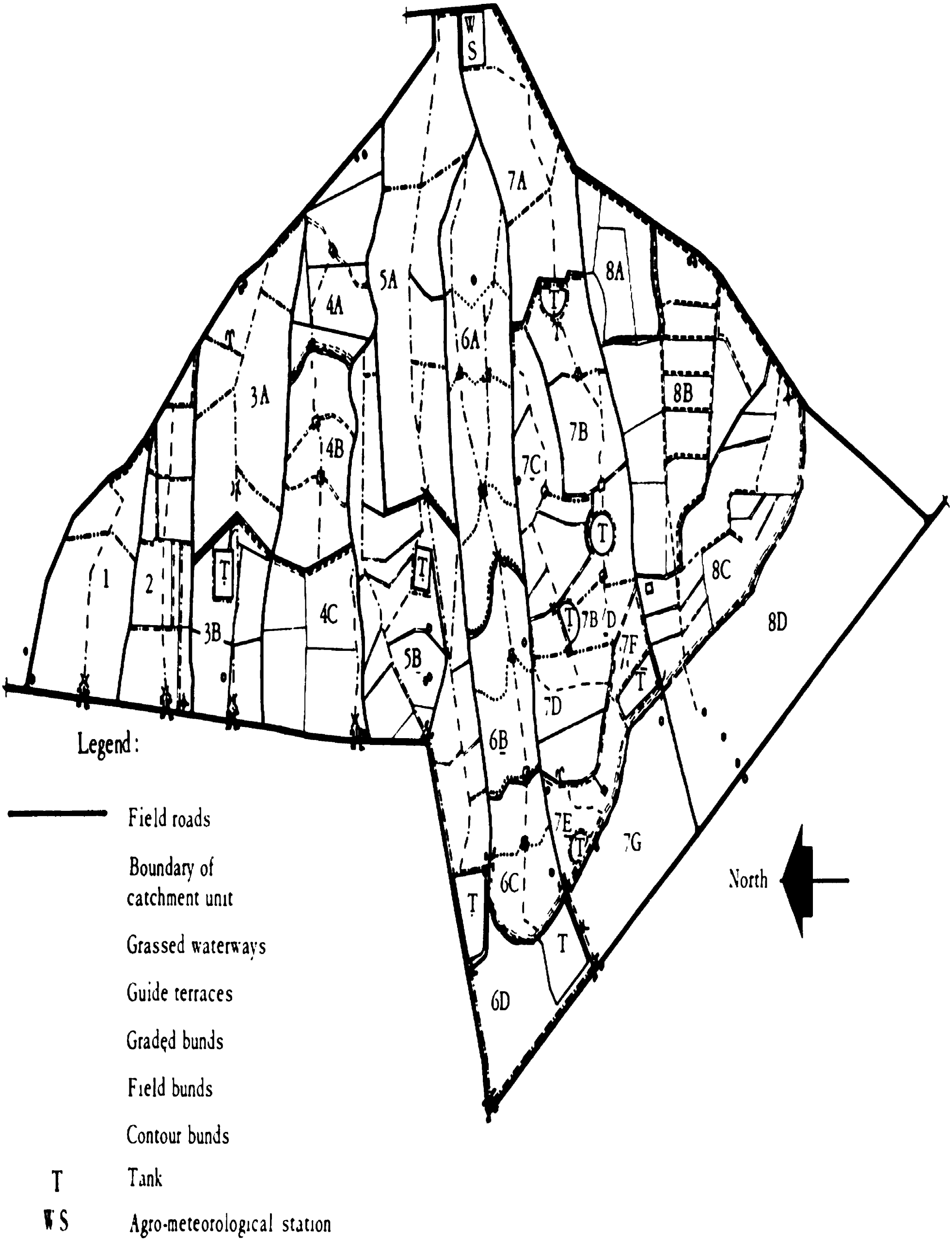



**Figure 43. Eight black-soil watersheds at ICRISAT Center.**

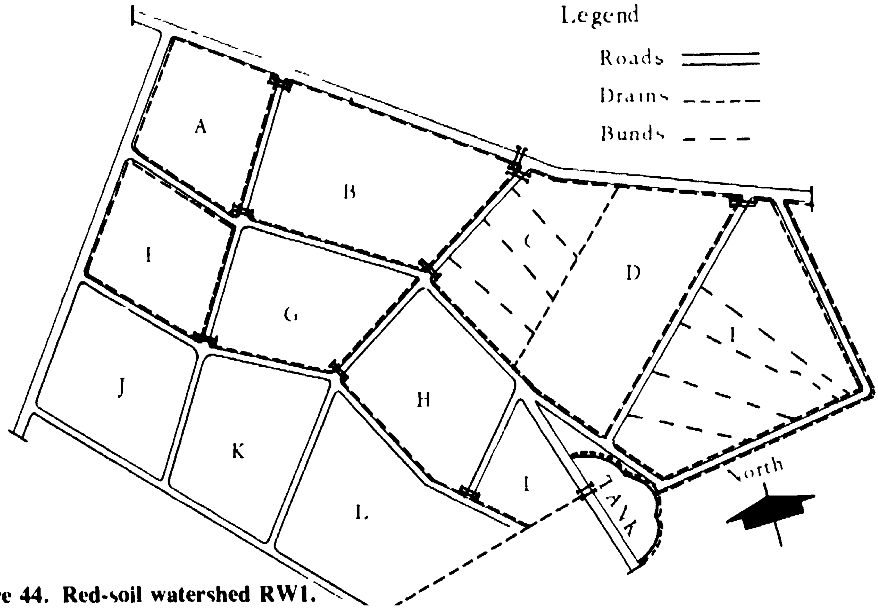



Figure 44. Red-soil watershed RW1.

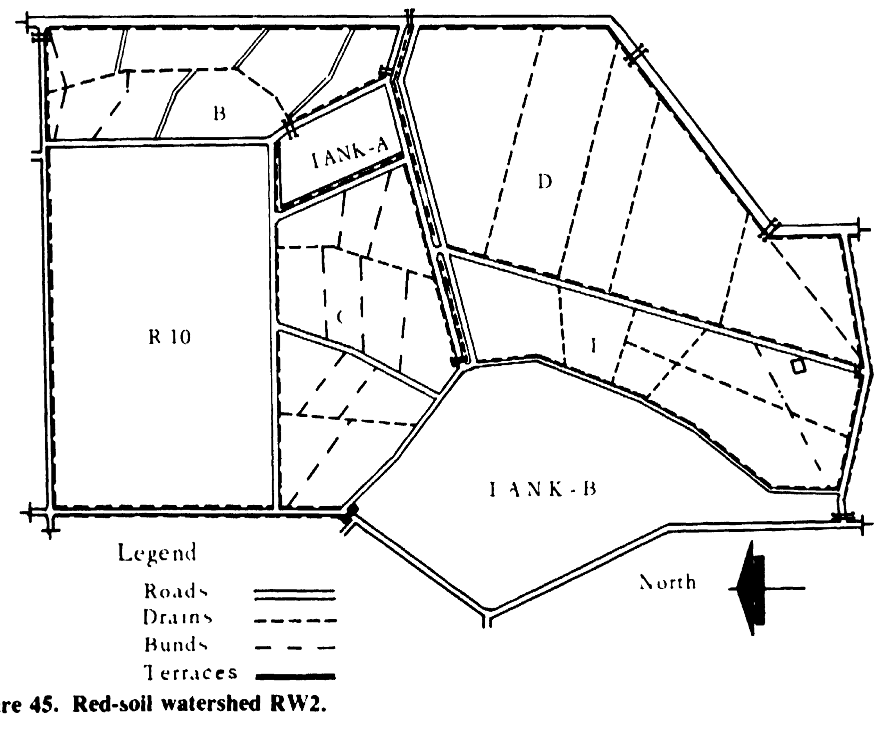



Figure 45. Red-soil watershed RW2.

**Land development.** On the undeveloped BW-7 watershed of 14.7 ha (Fig 46), past erosion had been serious and many gullies of 1 to 1.5 m depth existed (Fig 47). The total area in field bunds, gullies, and natural drainageways amounted to 10 percent of the watershed. Soils varied from deep to extremely shallow. Slopes of fields ranged from 1.25 to 3 percent.

The layout of the newly developed watershed superimposed over the original layout of the land is shown in Figure 48 (tanks will be discussed later; see Note). In most cases, only limited shifting of existing bunds and ditches was necessary to obtain a satisfactory design. The total area under previously existing bunds, ditches, and gullies amounted to 1.5 ha; after development the area under drainageways and graded bunds amounted to only .57 ha.

Land-development activities were initiated with a thorough plowing immediately after the harvest of rainy season crops. At this time the subsoil was still moist and the plowing created a loose surface mulch which prevented further evaporation from the subsoil, particularly where earth movement was required. It is difficult to remove extremely dry and hard black soil by means of animal-drawn equipment. Actual development was started in the last week of February 1975 and completed within 3 months, providing work for 40 to 50 laborers and 5 to 7 bullock pairs. This period coincides with the time during which labor and animals in rural areas are underemployed; therefore the opportunity costs may be much lower than those accepted for calculations.

The requirements and costs as monitored for different operations during the development of BW7 are summarized (Table 68). The normal plowing of fields, harrowing, and the final ridging of the land (items 1, 4, 8) (at Rs 330/ha) are associated with land preparation and therefore excluded from development costs. The total cost of land development (excluding water-storage facilities) is about Rs 575/ha. The maximum single cost factor is associated with the making of ditches and graded bunds (Rs 260/ha); land smoothing and gulley reclamation amounted to Rs 105/ha. In the development process, approximately 1 ha was reclaimed for cultivation; this benefit has not been included in the cost estimates. Only a very small portion of the total development costs (less than Rs 12/ha) were associated with actual capital expenditures.

The BW7 watershed was planted to several crops in the 1975 rainy and post-rainy seasons and the land- and water-management system

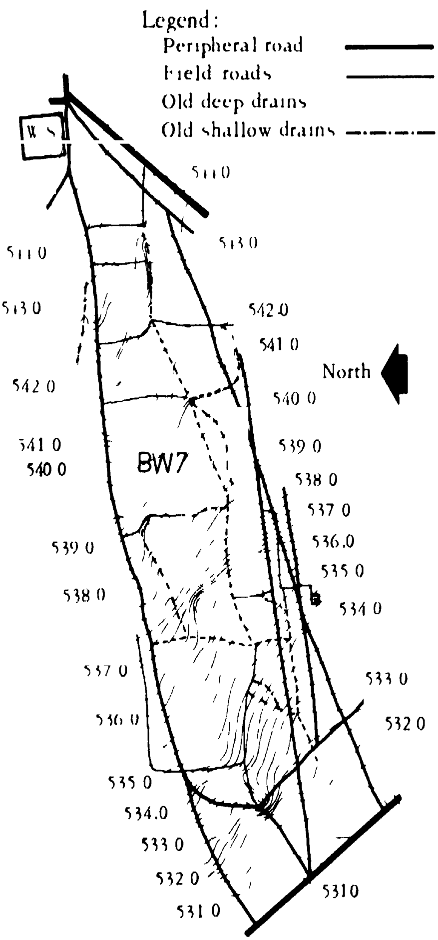



Figure 46. The BW7 area prior to development.

Note A tank is a relatively small artificial water reservoir constructed to collect and store surface runoff

*Figure 47. The BW7 watershed prior to development.*

designed and implemented. It was closely observed, and with minor exceptions, performed satisfactorily.

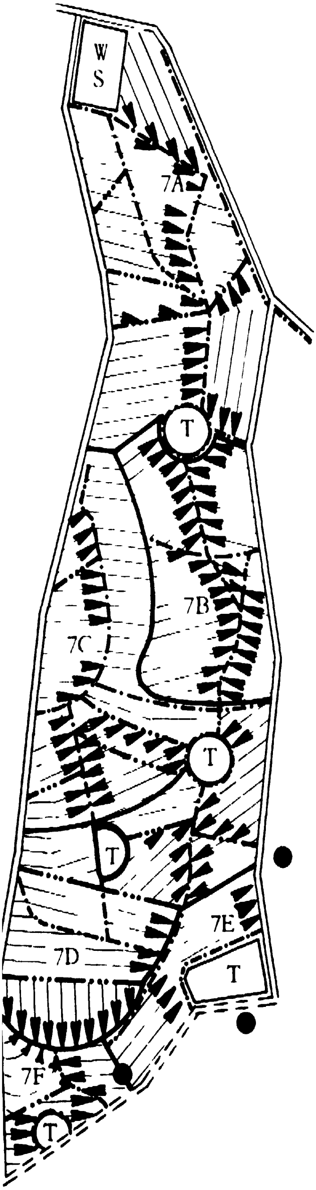
**Runoff storage development.** The first tanks built in research watersheds at ICRISAT were characterized by great depth (Annual Report, ICRISAT, 1973-1974). With these, the land area occupied is minimal, the evaporation losses are minimized, and the soil excavated can sometimes be used for filling depressions. However, such storage units provide very low storage-to-excavation ratios and high costs per unit of storage. In constructing tanks on BW-7, an effort was made to improve upon storage-to-excavation ratios.

The final locations for tanks on the BW7 watershed (Fig 48) were selected on the basis of topography (storage-to-excavation ratios), soils and subsoils (seepage), and requirements for a relatively equitable distribution of storage facilities. Tank sizes were decided on the basis of a preliminary estimate of the expected runoff (about 75 mm) in a normal year. Some of the design parameters and construction details have been summarized in Tables 69 and 70. The general procedure in tank construction

**Table 68. Land development cost on the BW7 watershed.**

| Operation | Implement used | Man days | Woman days | Bullock days | Total[a] (Rs) |
|---|---|---|---|---|---|
| 1. Plowing (fields) | Plow | 271.00 | — | 526.00 | 2797.50 |
| 2. Plowing (ditches) | Plow | 47.50 | — | 93.00 | 492.75 |
| 3. Plowing (field bunds) | Plow | 138.00 | — | 214.00 | 1263.00 |
| 4. Harrowing (fields) | Bakhare | 141.00 | — | 288.50 | 1500.00 |
| 5. Excavation (drains) | Scraper | 472.75 | 108.50 | 404.50 | 3774.88 |
| 6. Smoothing & reclamation | Scraper | 192.75 | 4.00 | 224.50 | 1556.87 |
| 7. Clearing bush and stones | — | 169.00 | 143.50 | — | 1334.50 |
| 8. Final land preparation | Ridger | 62.50 | — | 75.00 | 506.25 |
| 9. Drop structures, etc. | — | — | — | — | 175.00 |
| | | 1494.50 | 256.00 | 1825.50 | |
| Total costs | | 6725.25 | 1024.00 | 5476.50 | 13400.75 |
| Land preparation cost (1,4, and 8) | | 2135.25 | — | 2668.50 | 4803.75 |
| Net costs of land development | | 4590.00 | 1024.00 | 2808.00 | 8597.00 |

[a] Costs are calculated at ICRISAT Center wage rates: Rs 4.50 and Rs 4.00/day for male and female laborers and Rs 3/day for a bullock.




| Watershed | Area (ha) | Tank capacity (ha cm) | Slope (%) |
|---|---|---|---|
| BW7 A | 3.76 | 20 | 0.6 |
| BW7 B | 2.72 | 22.5 | 0.6 |
| BW7 C | 2.52 | 17.5 | 0.6 |
| BW7 D | 1.09 | 11 | 1.0 |
| BW7 E | 0.89 | --- | 0.6 |
| BW7 F | 0.69 | 5 | 1.0 |

Legend

Field roads
Watershed boundary
Grassed waterways
Guide terraces
Graded terraces
Direction of cultivation
Tank, well — T, ●
Agro-meteorological station — W S

North

**Figure 48. Black-soil watershed BW7, divided into six units with five runoff-storage facilities.**

**Table 69. Design parameters of tanks in the BW7 watershed.**

| Tanks | Bund top width (m) | Outside slope (V : H) | Inside slope (V : H) | Tank shape |
|---|---|---|---|---|
| BW7 A | 1.5 | 1 : 2 | 1 : 2 | Semicircular |
| BW7 B[a] | 1.5 | 1 : 1 | 1 : 1.5 | Circular |
| BW7 C | 1.0 - 1.5 | 1 : 2 | 1 : 2 | Semicircular |
| BW7 D | 2.0 | | | Rectangular |
| Upper bund | | 1 : 1 | 1 : 1 | |
| Side and lower bund | | 1 : 1.5 | 1 : 2 | |
| BW7 E | 0.5 | — | 1 : 1.5 | Semicircular |

[a] The inner side showed signs of slipping after first filling.

**Table 70. Construction details of five tanks in the BW7 watershed.**

| Sub-catchment: Tank No. | Area (ha) | Area occupied (ha) | Storage capacity (ha-cm) | Earth work ($m^3$) | Storage-to-excavation ratio | Maximum depth (m) |
|---|---|---|---|---|---|---|
| BW7 A | 3.76 | 0.13 | 2.00 - 20.0 | 850 | 2.35 | 2.35 |
| BW7 B | 2.72 | 0.20 | 2.25 - 22.5 | 900 | 2.50 | 2.25 |
| BW7 C | 2.52 | 0.20 | 1.75 - 17.5 | 600 | 2.90 | 1.50 |
| BW7 D[a] | 4.09 | 0.35 | 4.10 - 41.0 | 1630 | 2.50 | 2.00 |
| BW7 E | 0.89 | 0.05 | 0.50 - 5.0 | 500 | 1.00 | 1.50 |

[a] The BW7 D tank functions as the final storage of the entire watershed; all tanks except BW7 E spill into this tank.

was to use draft animals and scrapers to remove topsoil. Thereafter, labor was used to build the bunds (Fig 49). Compaction of the bund core-section to the original soil bulk-density was obtained by applying water and then using draft animals walking on top of the bund.

Costs incurred in the construction of tanks in BW7 have been summarized in Table 71. The total cost of construction of the four interconnected tanks in BW7 A, B, C, and D was about Rs 22 000 which amounts to Rs 216/ha-cm of storage. The cost of land occupied could be excluded, because no land was lost in the overall development process (only 1 ha was used for tank construction). The cost/ha-cm of storage was lowest for the BW7 C tank (Rs 157); the cost/ha-cm of storage obtained were Rs 237, 222, and 225 for the BW7 A, B, and D tanks, respectively. The costs of storage development for the medium deep, partly above-ground tanks ranged from Rs 15 700 to Rs 23 700 per ha-m. The cost of the entirely dug tank in BW7 F was Rs 489/ha-cm of storage or almost Rs 50 000/ha-m; this range of costs illustrates the relationships between construction costs and storage-to-excavation ratios.

The runoff-storage system implemented on the BW7 watershed was subjected to a rather severe test during rainy season 1975 No breaches of bunds occurred; all structures performed well even at times when large quantities of water were conveyed through the spillways. However, a number of observations were made which resulted in subsequent modifications to intercepting inlet channels

*Figure 49 Manpower and draft animals engaged in constructing tank on BW7*

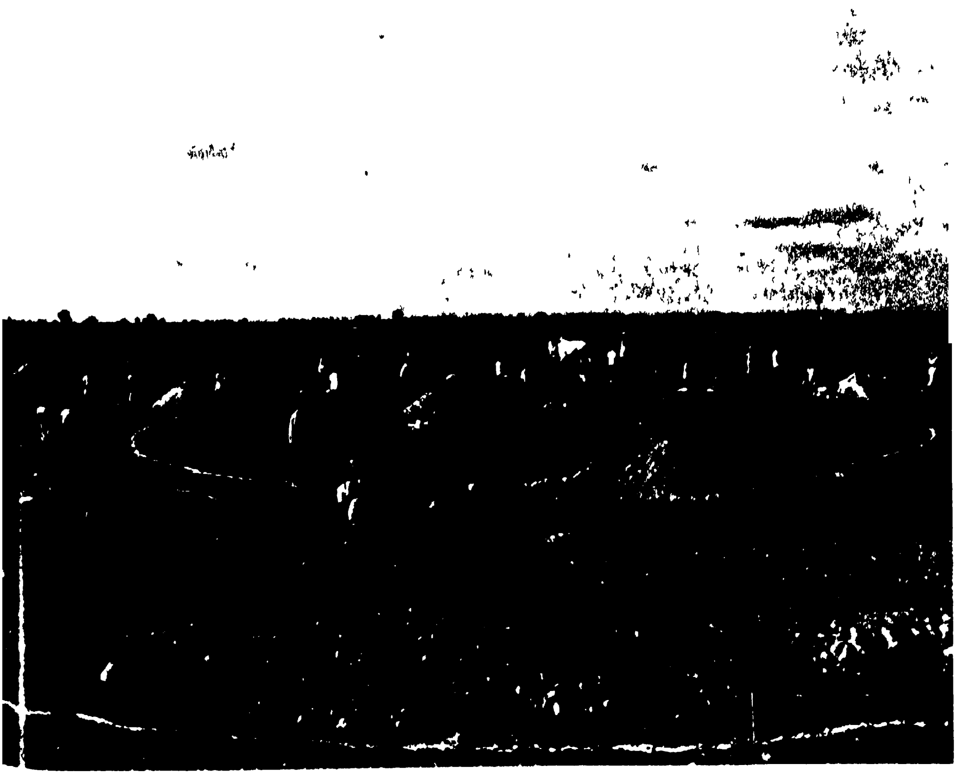


Table 71. Costs[a] of different operations in tank construction on BW7.

| Tank No. | BW7 A | BW7 B | BW7 C | BW7 D | BW7 E |
|---|---|---|---|---|---|
| | (Rs) | (Rs) | (Rs) | (Rs) | (Rs) |
| Scraping | 203 | 354 | — | 496 | — |
| Digging and bund construction | 2411 | 2306 | 1501 | 5784 | 1591 |
| Wetting and compaction | 513 | 506 | 214 | 1583 | 11 |
| Bund shaping[b] | 751 | 136 | 176 | 366 | 189 |
| Inlet construction[c] | 663 | 1700 | 861 | 1027 | 656 |
| Total costs | 4741 | 5003 | 2752 | 9256 | 2447 |
| Cost/ha-cm of storage | 237 | 222 | 157 | 225 | 489 |
| Cost of land under tank[d] | 650 | 1000 | 1000 | 1750 | 250 |
| Total cost of tanks | 5191 | 6003 | 3752 | 11006 | 2697 |
| Cost/ha-cm of storage | 259 | 267 | 274 | 268 | 539 |

[a] At ICRISAT Center wage rates, opportunity costs might be substantially lower

[b] High in case of BW7 A, because of the application of a wider core section.

[c] Some adaptations were made after rainy season 1975; the costs are those of the finally accepted designs.

[d] At an estimated cost of Rs 5000/ha.

## Water Balance Studies

### Runoff

Runoff data from the black-soil watersheds is presented in Table 72. Since the storm of 9 September very significantly affected total runoff, runoff excluding that of this storm was also computed. In watersheds cultivated to a 0.4- or 0.6-percent graded ridge-and-furrow system, runoff amounted to less than or about 15 percent of the rainy-season rainfall; if the 9 September storm is ignored, this value falls to less than 4.5 percent. Ridge-and-furrow slopes equal to or exceeding 0.8 percent increased runoff quite substantially, although serious erosion was not observed.

The runoff under monsoon-fallow field-bunded conditions (BW4 B) amounted to 24 percent of the rainy-season rainfall (Table 72). The runoff from BW6 B, a fallow contour-bunded watershed, was relatively small–due in part to the quantities of stagnant water stored along the contour bunds (Fig 35). Since the soil profile was filled to capacity by early August, this ponded water evaporated and/or contributed to groundwater recharge.

Table 72. Runoff on black-soil watersheds, rainy season 1975.

| BW[a] | Treatment | Including 9 Sep storm Rainfall | Runoff | Runoff | Excluding 9 Sep storm Rainfall | Runoff | Runoff |
|---|---|---|---|---|---|---|---|
| | | (mm) | (mm) | (% of RF) | (mm) | (mm) | (% of RF) |
| 1 | R/F 0.6% | 1042 | 161 | 15.5 | 884 | 39 | 4.4 |
| 2 | R/F 0.6%, bunds | 1047 | 127 | 12.0 | 891 | 24 | 2.7 |
| 3A | R/F 0.4% | 1040 | 120 | 11.5 | 881 | 26 | 2.9 |
| 3B | R/F 1% | 1049 | 193 | 18.4 | 895 | 63 | 7.0 |
| 4A | Flat gr. bunds | 1044 | 150 | 14.3 | 887 | 25 | 2.8 |
| 4B | Fallow, bunds | 1055 | 253 | 24.03 | 904 | 114 | 12.6 |
| 5A | R/F 0.8% | 1041 | 195 | 18.7 | 885 | 63 | 7.1 |
| 6B[b] | Fallow, ct. bunds | 1031 | 176 | 17.4 | 877 | 55 | 6.3 |
| 8A | Field bunds | 1030 | 62 | 6.0 | 879 | 2 | — |

[a] Due to malfunctioning of water-level recorders and the effect of temporary storage above contour bunds, reliable runoff data were not obtained on BW6 A and BW6 C.
Runoff, estimated from tank records on BW7 A,B,C,D, and E amounted to 88, 105, 146, and 157 mm, respectively.

[b] Measured runoff from BW6 B was not adjusted for the quantities stored above contour bunds during successive storms.

Runoff data collected from different red-soil watersheds are summarized in Table 73. The red soils were observed to be characterized by quite-high rates of peak runoff. On 24 September a peak discharge of 0.157 $m^3$/sec/ha was measured in the cropped watershed RW1 D, this is slightly higher than the maximum value obtained for a fallow black deep soil (BW4 B).

In summary, the total seasonal runoff volumes in cropped and ridged deep black-soil watersheds (of moderate grade) was in the range of 10 to 15 percent of the rainy-season rainfall. On shallow black soils, under similar conditions, runoff amounted to about 10 percent. On cropped and ridged red soils however, runoff amounted to between 25 and 30 percent.

### Soil Erosion

Table 74 presents soil losses from black-soil watersheds. Although substantial erosion within watersheds was observed under fallow conditions (Fig 35), the erosion measured at outlets was of small magnitude. The runoff and soil loss in red soils was higher than in the black soils. Total soil losses on broad-ridged red-soil watersheds at 0.6 percent slope were 4.3 to 4.8 metric tons/ha.

Table 73. **Runoff data, with and without the storm of 9 September, on red-soil watersheds, rainy season 1975.**

| RW | Treatment | Including 9 Sep storm Rainfall | Runoff | Runoff | Excluding 9 Sep storm Rainfall | Runoff | Runoff |
|---|---|---|---|---|---|---|---|
| | | (mm) | (mm) | (% of RF) | (mm) | (mm) | (% of RF) |
| 1 C | Gr. bunds | 1 103 | 165 | 14.9 | 940 | 114 | 12.2 |
| 1 D | Br. ridges 0.6% | 1 104 | 307 | 27.8 | 946 | 175 | 18.5 |
| 1 F | Cont. bunds | 1 103 | 97 | 8.7 | 946 | 56 | 6.0 |
| 2 A | Uncontrolled grazing | 1 109 | 245 | 22.3 | 959 | 121 | 12.6 |
| 2 B | Br. ridges 0.6% | 1 109 | 338 | 30.4 | 969 | 224 | 23.1 |
| 3 | Native vegetation | 1 221 | 91 | 7.4 | 1 081 | 31 | 2.9 |

**Groundwater**

Observations on groundwater levels show an increase of about 50 cm between May 1975 and May 1976 (Fig 50). On black deep soils, the amount of water percolated through the root profile is estimated to be approximately 225 mm, or nearly 20 percent of the seasonal rainfall. On black shallow soils the groundwater response to rainfall is considerably earlier than on deep soils (Fig 51); the contribution to groundwater may be estimated at 350 mm, or 30 percent of the rainfall (some of this may have been caused by deep seepage from nearby tanks). Perched water tables were observed during August; at the end of October, groundwater was present within 1 m of the soil surface at some locations.

**Crop Evapotranspiration**

The even distribution of rainfall throughout the season justifies the assumption that actual evapotranspiration has taken place at rates very near to potential (open-pan) evapotranspiration. Thus, the evapotranspiration during the rainy growing season (standard weeks 26 to 39) can be calculated at approximately 420 mm. Although, except in intercropped areas, a new crop was established during October and November, the extended monsoon rainfall was very uniformly distributed and it may be presumed that evapotranspiration from standard weeks 40 to 44 also took place at nearly potential rates. The computed potential evapotranspiration for this 5-week period amounts to approximately 130 mm.

Beginning in November, available soil moisture started to decline and evapotranspiration therefore did not take place at potential rates. One weighing lysimeter had been installed on BW3 during the rainy season. A sorghum crop was established in mid-October (standard week 42). The measured evapotranspiration from the lysimeter after standard week 47 amounted to approximately 125 mm.

Combining the estimates for evapotranspiration during the rainy and post-rainy seasons

Table 74. Erosion on black-soil watersheds, rainy season 1975.

| Watershed | Treatment | Soil loss (metric ton/ha) |
|---|---|---|
| BW1 | R/F at 0.6% | 0.29 |
| BW2 | R/F at 0.6% (field bunds) | 0.19 |
| BW3 A | R/F at 0.4% | 0.11 |
| BW3 B | R/F at 1.0% | 1.20 |
| BW4 A | Flat, graded bunds | 0.24 |
| BW4 B | Flat, post-rainy season fallow | 2.51 |
| BW5 A | R/F at 0.8% | 0.59 |

1975, the total actual evapotranspiration of a double-crop system consisting of short duration rainy and post-rainy season crops amounts to approximately 675 mm. When only a rainy season crop was grown, the total amount of water used probably did not exceed 500 mm, even with somewhat longer duration varieties. For single post-rainy season 1975 cropping, the total evapotranspiration ranged between an estimated 250 and 300 mm.

### Runoff Collection and Use

All tanks were full at the end of September (substantial quantities of runoff water were lost through tank spillways). Due to an extended rainy season 1975, supplemental water was not required before late November and December. Unfortunately, seepage losses caused all water to disappear in the BW7 A, B, and C tanks before post-rainy season utilization was needed. However, on the BW3 A, BW5 A, BW7 D, BW7 E, RW1, and RW2 watersheds, a portion of the collected runoff water was utilized.

Irrigation from black-soil tanks, where seepage rates were low, amounted to only 62 percent of the total runoff collected on BW3 and to 69 percent on BW5 A; in terms of equivalent depth across the contributing watershed, this would amount to 52 and 40 mm, respectively. Irrigation from the RW1 tank on red soil amounted to 62 percent of the collected runoff and provided 60 mm of water across the contributing watershed.

Present pipe conveyance systems (i.e., aluminum) are efficient in labor use, but expensive in terms of investment. High-density polyethylene (HDPE) pipes (10-cm diameter)

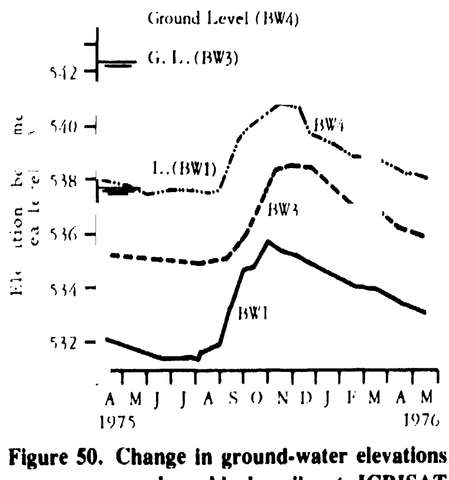



Figure 50. Change in ground-water elevations on deep black soils at ICRISAT Center, April 1975 through May 1976.

were tested on black soils. These pipes are relatively low (Rs 12/m) in cost, flexible, light-weight, rodent-proof, and low in flow-resistance. A prototype of a low-cost leak-proof coupling (Fig 52) was designed and fabricated; this coupling requires a marginally higher labor input. Where the present cost of aluminum pipe with couplers is about Rs 34.70/m, the HDPE pipe system (with present couplers) would cost about Rs 18/m.

Yield responses to supplemental irrigation on the research watersheds differed substantially between crops. Post-rainy season 1975 sorghum consistently responded to irrigation at the grain-filling stage; on BW3A the yield increased from 2 570 kg/ha under residual moisture conditions to 3 570 kg/ha when a single 50-mm irrigation was applied. Tomatoes planted in millet stubble yielded 12.7 metric tons/ha on broad ridges on RW1D and 10.4 metric tons/ha on flat-planted RW1E. One 25-mm irrigation increased tomato yields to 17.2 and 12.5 metric tons/ha on RW1D and E, respectively; the lower response in the latter case was partly due to problems in attaining a uniform water distribution under flat-planted conditions. The gross irrigation returns on tomato can be estimated at Rs 1 134 and Rs 580 per ha-cm on broad-ridged RW1D and on flat planted RW1E, respectively.

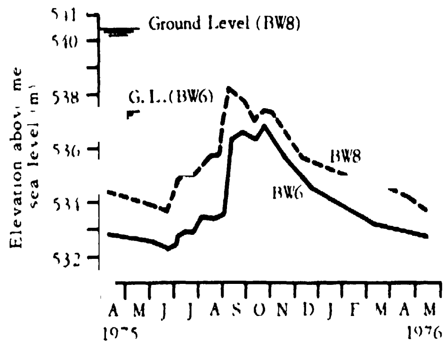



**Figure 51. Change in ground-water elevations on medium-deep and shallow black soils at ICRISAT Center, April 1975 through May 1976.**

*Figure 52. Newly designed coupler for use with high-density polyethylene water conveyance systems.*

**Water Balances and Effective Rainfall**

On deep black soils during rainy season 1975, the BW1 watershed (double-cropped, cultivated to a 0.6-percent graded ridge-and-furrow system) was characterized by a total evapotranspiration during the growing season which, in those areas where a good second crop was established, amounted to approximately 675 mm. Thus, the effective rainfall amounted to about 65 percent of the rainy-season rainfall. Of the remaining portion of the total seasonal precipitation, approximately 15 percent was lost as runoff while about 20 percent percolated down to groundwater. The double-cropped watersheds BW2 and BW4A were characterized by similar water balances.

Double-cropped watersheds on shallow to medium deep black soils were characterized by less total runoff; in case of moderate grades (0.4 to 0.6%) runoff was about 10 percent. The groundwater component was, however, substantially larger at approximately 30 percent of the seasonal rainfall (a portion of this may have been caused by tank seepage). Actual evapotranspiration on these watersheds amounted to about 60 percent of the monsoon rainfall or about 625 mm. The lower effective rainfall in these soils is primarily due to decreased profile-moisture withdrawal in the post-rainy season as is evidenced by soil-moisture records.

Double-cropped watersheds on red soils, cultivated to graded ridges and furrows, had a greater total runoff of approximately 30 percent (RW1 D and RW2 B). Runoff from contour-bunded or graded-bunded watersheds was less, the reduced runoff during rainy season 1975 produced an increase in groundwater recharge. The seasonal evapotranspiration on red soils may be estimated by adding to the calculated potential evapotranspiration from the end of June to early November (550 mm) the recorded profile-moisture decrease in the post-rainy growing season (about 50 mm). Effective rainfall in this situation may therefore be estimated at approximately 600 mm, or about 55 percent of the rainy-season rainfall (on red soils, 1 100 mm). This remaining portion (about 15%) contributed to groundwater.

The traditional farming systems contributed to a reduced effective rainfall. On black shallow soil, rainy-season cropping on BW8 A resulted in a very low runoff of about 6 percent. The rainy-season sorghum crop, harvested in early November, resulted in a total evapotranspiration of approximately 550 mm. The effective rainfall may therefore be estimated at about 50 percent. The remaining 45 percent of the rainy-season rainfall contributed to groundwater. Rainy-season fallow post-rainy season cropping under traditional technology resulted in greatly increased runoff (25%), while the total evapotranspiration of the post-rainy season crops probably amounted to less than 275 mm or about 25 percent of the rainy-season rainfall; a substantial portion (around 30%) of the rainy-season rainfall was lost in terms of evaporation from soil and transpiration by weeds.

## Crop Production in Research Watersheds

The objective of the cropping-systems phase of the resource utilization research program is to develop systems which can effectively utilize the current season's rainfall, either directly from the soil or indirectly through recycling of surface-stored water and/or groundwater. Alternate cropping systems must be studied in field-scale operational units to develop means of improving production, while at the same time reducing labor and draft-power demands. The development of improved "non-monetary" management systems which will optimize returns from improved seed and moderate levels of fertilization, plant protection, and animal-drawn farm equipment are being emphasized.

### Crop Production on Black Soils

The most striking contrast in watersheds on deep black soils is the difference between conventional rainy-season fallow, either with traditional technology or improved technology, compared to double-cropping during the rainy and post-rainy seasons (Table 75). In the maize-chickpea double-cropping system (Fig 53), the gross value for the two seasons was Rs 4 650/ha, while the monetary value of the various traditional post-rainy season cropping sys-

*Figure 53. Sequential plantings of chickpea and sunflower in maize stubble.*

tems, even with improved technology, ranged from only Rs 400 to 1 570. Chickpea, a legume, showed very little yield difference between "traditional technology" and "improved technology" (Table 75).

In order to get an evaluation of the yield differences between flat and narrow-ridge (75-cm) planting under an improved-technology system, the crop yields of all watersheds with ridged vs flat-planting systems were combined. In the sole-crop system, the percentage yield increase of ridge over flat planting was 20.7 and 10 percent, respectively, for pearl millet and maize.

However, in the intercropping system the reverse was true and yields in the ridged planting was 2.4 and 14 percent less than flat planting for Setaria and pigeonpea, respectively.

The main reason for the lesser yield in the 75-cm ridged planting in the intercropping system was the reduced plant stand due to the difficulty of planting a row of each intercrop 25

**Table 75. Grain yields and rupee values of double-crop systems vs rainy season fallow and single crop in black-soil watersheds (BW1, BW8), rainy and post-rainy season 1975.**

| Rainy season | | Post-rainy season | | Gross value[c] for rainy + post-rainy season crops |
|---|---|---|---|---|
| Crop | Yield (kg/ha) | Crop | Yield (kg/ha) | (Rs/ha) |
| Maize | 3 880 | Chickpea[a] | 1 290 | 4 650 |
| Fallow | 0 | Chickpea[a] | 1 310 | 1 570 |
| Fallow | 0 | Chickpea[b] | 1 060 | 1 270 |
| Maize | 3 880 | Sunflower[a] | 660 | 4 090 |
| Fallow | 0 | Sunflower[a] | 270 | 410 |
| Fallow | 0 | Sunflower[b] | 370 | 560 |
| Pearl millet | 2 110 | Sorghum[a] | 1 700 | 2 860 |
| Fallow | 0 | Sorghum[a] | 2 110 | 1 570 |
| Fallow | 0 | Sorghum[b] | 770 | 580 |
| Pearl millet | 2 110 | Safflower[a] | 1 000 | 3 080 |
| Fallow | 0 | Safflower[a] | 850 | 1 280 |
| Fallow | 0 | Safflower[b] | 260 | 390 |

[a] Improved technology (see Table 61)

[b] Traditional technology (see Table 61)

[c] Prices in Rs/100 kg received at time of harvesting: maize, 80; sorghum and pearl millet, 75; chickpea, 120; safflower and sunflower, 150.

cm apart on this narrow ridge. This problem was eliminated in the broader (150-cm) ridge-and-furrow system in the red soil (Fig 54).

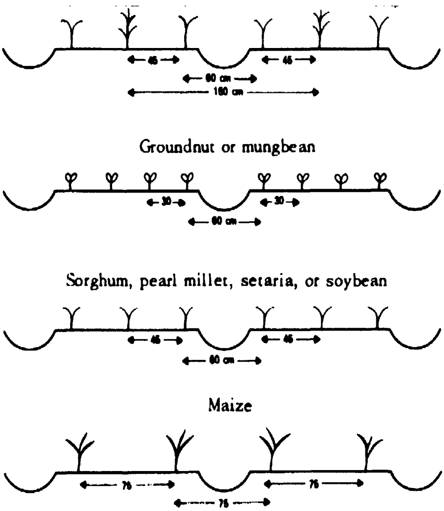



**Figure 54. Possible cropping systems on broad ridges and furrows.**

### Crop Production in Red Soils

Grain yields and total rupee values of rainy and post-rainy crops are presented in Table 76. Pearl millet followed by a post-rainy tomato crop produced a gross value of Rs 9370/ha, which was by far the highest monetary value of any system. Gross values of the Rs 4000 range were obtained in several double-cropping systems, including sorghum-pigeonpea intercrop, groundnut-safflower and groundnut-chickpea. It is recognized that the late rainy season was wetter than normal, and thus post-rainy season crops were better than would normally be expected without supplemental irrigation.

During high-intensity rains in 1974, the narrow (75-cm) ridge-and-furrow systems in red soils tended to "slake down" and thus cross-furrow erosion occurred. To avoid this, a 150-cm broad ridge-and-furrow system was established on red soils, in RW1D, RW2B, and RW2E. In spite of many storms abnormally high in intensity, there was no cross-furrow erosion with the broad ridge-and-furrow system. This feature, plus agronomic flexibility, makes the broad ridge and furrow a highly desirable alternative to the narrow ridge-and-furrow system.

In the grassed waterways, paragrass appears to have many desirable features–including quick establishment, erosion control, longevity during the hot dry season, quick recovery at the onset of the rainy season, and high production of palatable green forage.

### Rainfall-use Efficiency

Attaining the best possible use of the total seasonal rainfall by means appropriate for the farmer of the SAT is the basic objective of the Farming Systems research program. An attempt has been made to obtain preliminary estimates of the RUE (rainfall-use efficiency) achieved by alternative systems of farming. Although ideally RUE should be expressed in terms of the quantity of food produced, for purposes of comparison all yields were converted to rupee values. Rather than calculating the RUE for all watersheds and cropping systems, only the highest and lowest values for selected watersheds have been determined. The estimated RUE values are summarized in Table 77.

On the black soils, a maximum RUE value of Rs 62/cm would have been obtained by a sequential maize-sorghum cropping system on 0.4 percent graded ridges with supplemental irrigation on sorghum. Under conditions in which no runoff water could be utilized, sequential cropping of rainy season maize and post-rainy season chickpea produced the highest RUE values on deep as well as on shallow black soils. In double-crop systems, the Setaria-pigeonpea intercrop system resulted in the lowest RUE values on black soils. On black deep soils the RUE increased from Rs 46/cm on flat-planted BW4 A to Rs 58/cm on BW3, which was cultivated in ridges and furrows.

Table 76. Grain yield and total gross-rupee values of the rainy plus post-rainy 1975 intercrops vs various double-crop systems on red-soil watersheds (RW1 C, D, E, and RW2 B).

| Rainy season | | Post-rainy season | | Gross rupee value of rainy + post-rainy crops |
|---|---|---|---|---|
| Crop[a] | Yield (kg/ha) | Crop[a] | Yield (kg/ha) | (Rs/ha)[b] |
| Red-soil watersheds (RW1 C,D,E): | | | | |
| Sorghum, inter | 3470 | Pigeonpea, inter | 1190 | 3911 |
| Sorghum, sole | 4670 | Sorghum, ratoon | 630 | 3975 |
| Pearl millet, sole | 2750 | Safflower, sequent | 630 | 3007 |
| Pearl millet, sole | 2750 | Tomato, sequent | 11600 | 9370 |
| Groundnuts, sole | 1860 | Chickpea, sequent | 250 | 4020 |
| Groundnuts, sole | 1860 | Safflower, sequent | 840 | 4980 |
| Red-soil watershed (RW2 B): | | | | |
| Sorghum, inter | 3000 | Pigeonpea, inter | 1820 | 4252 |
| Sorghum, sole | 3590 | Sorghum, ratoon | 300 | 2917 |
| Setaria, inter | 1250 | Pigeonpea, inter | 1780 | 2583 |
| Pearl millet, sole | 2180 | Sorghum, sequent | 2020 | 3150 |
| Pearl millet, sole | 2180 | Safflower, sequent | 630 | 2580 |
| Groundnuts, sole | 1740 | Mustard, sequent | 180 | 3840 |

[a] Inter refers to intercropping; sole to sole cropping; ratoon to ratoon cropping; sequent to sequential cropping (second crop is planted immediately after harvest of the rainy-season crop).

[b] Based on prices (Rs/100 kg) received at harvest: sorghum and pearl millet, Rs 75; pigeonpea, Rs 110; chickpea, Rs 120; safflower, Rs 150; groundnuts Rs 200; toria, Rs 180; setaria, Rs 50; and tomatoes, Rs 63.

**Table 77. Rainfall-use efficiencies obtained in alternative farming systems[a] on red-soil and on black-soil watersheds, rainy and post-rainy seasons 1975.**

| Watershed | Cropping system | Crop production[b] | | Value | RUE |
|---|---|---|---|---|---|
| | | Rainy | Post-rainy | | |
| | | (kg/ha) | (kg/ha) | (Rs/ha) | (Rs/cm) |
| Highest values obtained in each respective watershed: | | | | | |
| BW1 | Maize, chickpea | 4 830 | 1 790 | 6 012 | 58 |
| BW3 A | Maize, sorghum[c] | 4 770 | 3 570 | 6 493 | 62 |
| BW4 A | Maize, chickpea | 3 680 | 1 510 | 4 756 | 46 |
| BW4 B | Fallow, sorghum | — | 2 190 | 1 642 | 12 |
| BW6 B | Fallow, sorghum | — | 2 190 | 1 642 | 16 |
| BW6 C | Maize, chickpea | 3 980 | 1 290 | 4 732 | 45 |
| BW7 C | Maize, chickpea | 4 560 | 1 120 | 4 992 | 48 |
| BW8 A | Sorghum-pigeonpea | 1 040 | 500 | 1 184 | 11 |
| RW1 C2 | Pearl millet, tomato | 2 750 | 2 000 | 14 362 | 130 |
| RW2 B | Sorghum-pigeonpea | 3 000 | 1 820 | 4 252 | 39 |
| Lowest values obtained in each respective watershed: | | | | | |
| BW1 | Setaria-pigeonpea | 1 170 | 1 260 | 1 872 | 18 |
| BW3 A | Setaria-pigeonpea | 1 170 | 1 820 | 2 587 | 25 |
| BW4 A | Setaria-pigeonpea | 1 270 | 1 870 | 2 692 | 26 |
| BW4 B | Fallow, safflower | — | 260 | 390 | 4 |
| BW6 B | Fallow, safflower | — | 270 | 405 | 4 |
| BW6 C | Setaria-pigeonpea | 1 750 | 1 120 | 2 107 | 20 |
| BW7 C | Setaria-pigeonpea | 390 | 420 | 657 | 6 |
| BW8 A | Sorghum | 110 | — | 88 | 1 |
| RW1 C2 | Pearl millet, safflower | 2 830 | 630 | 3 067 | 28 |
| RW2 B | Pearl millet, safflower | 2 180 | 630 | 2 580 | 23 |

[a] Total rainy season rainfall for the black-soil watersheds has been estimated (from the average of many rain gauges) at 1 040 mm and for red-soil watersheds at 1 100 mm.

[b] Only the yields at the optimum N level (80 N) were considered for computation.

[c] Although in BW3 A maize and sorghum were not actually grown as sequential crops, this combination would have resulted in the maximum RUE with irrigation to sorghum.

The traditional farming systems of single cropping in the rainy or post-rainy seasons resulted in much-lower RUE values. Of these systems (simulated in BW4 B, BW6 B, and BW8 A), rainy season fallow post-rainy season cropping on BW6 B resulted in a maximum RUE of only Rs 16/cm. A minimum RUE value of Rs 1/cm was obtained in BW8 A under rainy season sorghum post-rainy season fallow.

On the red soils, the maximum RUE value (130) was obtained in RW1 B where pearl millet in the rainy season was followed by supplementally irrigated tomato in the post-rainy season with crop cultivation on 0.6-percent graded broad ridges (150 cm wide). Under non-irrigated conditions in RW2 B the sorghum-pigeonpea intercrop resulted in an RUE of Rs 39/cm. The lowest RUE values on red soils were obtained by a sequential cropping system of pearl millet followed by safflower.

The range of RUE values obtained on black soils (from 1 to 62) illustrates the production potential of this type of environment in the SAT, given the perfection and introduction of improved technology. It may be concluded that on black deep and medium-deep soils during high and medium rainfall years, with runoff storage available, a maize-sorghum sequential-cropping system needs to be further explored. Without supplemental water, the greatest gross returns may be expected from sequential (or if necessary, relay) cropping of maize and chickpea. On the red soils, where the probability of moisture stress during the rainy season is much greater, supplemental irrigation to break a drought or to carry high-value crops in the post-rainy season might substantially increase RUE values.

#### Looking Ahead in Resource Utilization Research

Research on better management of natural resources to increase and stabilize rainfed agriculture will be continued and intensified at the ICRISAT Center. Efforts will be made to more-fully exploit the potential of the storage capacities of soil profiles by the development and adoption of suitable cropping systems and land-management techniques. Intercropping and minimum-tillage systems for sequential cropping will receive increased attention. The use of supplemental water to backstop rainfed agriculture will be further explored, as will the potentialities for increasing rainfall-use efficiency.

In the watershed units, the number of cropping systems studied will be reduced and two or more replications of each cropping system will be employed in order to increase the reliability of crop-yield measurements.

The broad ridge-and-furrow system will be investigated on a wider scale in the red and black soils.

Other research institutions will be requested to cooperate in the generation of meaningful models to extrapolate research results across diverse agro-climatic regions. Certain components of resource-utilization research will now be carried out at various locations in the Indian SAT (see Cooperative Research). Opportunities to test improved systems of farming under real-world conditions so as to determine their social implications will be sought and evaluated.

## Cooperative Research

ICRISAT is one of the international research centers where new concepts, approaches, and methodologies aimed at improved farming systems will be generated. However, before being ready for application in the many and diverse SAT regions of the world, these systems have to be integrated into viable packages and adapted into applicable site-specific technology through cooperative research.

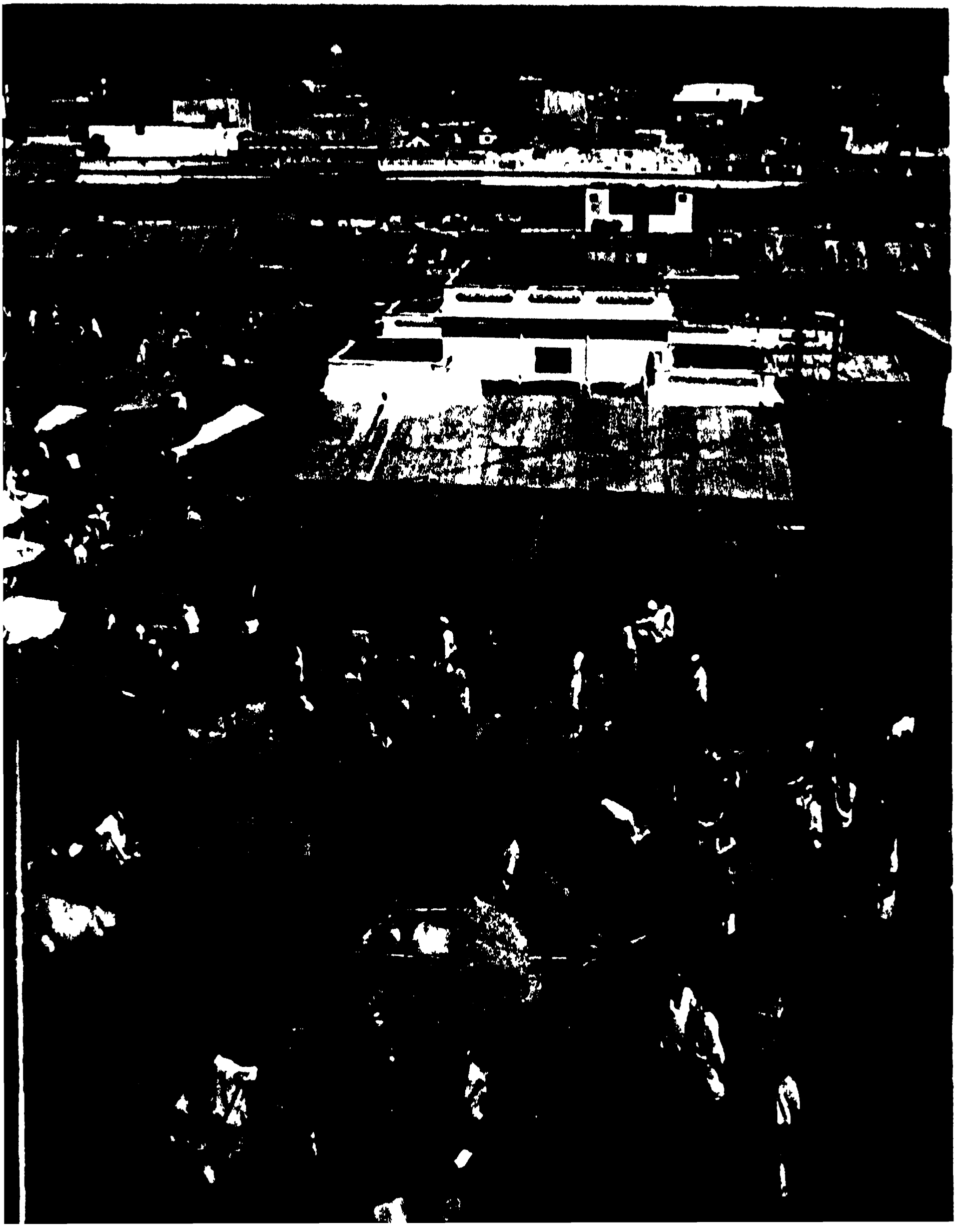
Simulation techniques are used to quantify and predict the hydrologic behavior of agroclimatic environments under alternative resource-management technologies. Basic information on crops and cropping systems, developed in various national programs, is used to match improved systems to the resources of a region. These studies will greatly reduce the number of research approaches necessary to evolve viable farming systems. For effective simulation studies, a limited number of "bench mark" locations must be identified. The diversity encountered in the SAT (climate, soil, people, livestock, capital) dictates the need for associated research efforts at such locations.

During the past year, discussions with leaders of Indian research programs[1] have resulted in two cooperative proposals to be initiated at several locations across the Indian SAT. The first, entitled "Hydrologic studies to improve land and water utilization in small agricultural watersheds," has as its objective the derivation of region-specific design criteria for improved resource management which more-effectively conserves and utilizes the rainfall and the soil and which, when integrated with new crop-production systems, will increase productivity and assure dependable harvests.

The second, entitled "Research on resource development, conservation, and utilization in rainfed areas," has as its objective development of a research program for testing the ridge-and-furrow system of cultivation and its modifications under several agro-climatic conditions and also to quantify the production effects of presently accepted soil- and water-conservation practices.

[1]The All India Coordinated Research project for Dryland Agriculture and the Central Soil and Water Conservation Research and Training Institute

# AGRICULTURAL ECONOMICS



# Agricultural Economics

The primary goal of the Agricultural Economics department is the identification of socio-economic and other constraints to agricultural development in the SAT (semi-arid tropics) and evaluation of alternative means of their alleviation via technological and institutional changes. This general philosophy expresses itself through the various research projects undertaken in the two major subject-matter areas of production economics and marketing economics. In this abridged report, we describe only the significant results from research, hence not all projects are covered.

## Production Economics

Seven projects are operating in this area; six were reported upon last year (Annual Report, ICRISAT, 1974-1975). The seventh, "Approaches to Organization and Group Action for Improved Land and Water Resource Utilization in the SAT," was initiated in October. Four production economics projects are reported in the following pages.

### Studies of Traditional Cultivation Practices and Resources Availabilities in SAT, India

ICRISAT initiated its VLS (village-level studies) at six Indian locations in May, 1975. The project is broadly governed by the assumption that one of the efficient ways to identify relevant elements for incorporation in prospective technologies generated by ICRISAT is to thoroughly understand the traditional system of farming in representative SAT areas.

Results thus far indicate there are considerable differences between SAT regions and villages within regions in terms of resource availabilities. The land/man ratio and average size of operational holdings is inversely related to the average annual rainfall and extent of irrigation. The average operational size of holdings in the six selected villages ranges from 2.8 ha in the more-irrigated red-soil village of Dokur in Andhra, to 7.7 ha in the low-rainfall black medium-deep soil village of Kalman in Maharashtra. The intra-village distribution of land holdings shows the same extent of skewness in each village, despite large differences in average size. Twenty percent of households operate 55 percent of the land; the remaining 80 percent of the households operate 45 percent of the land. Ignoring equity considerations, the larger (and consolidated) holdings may be the most conducive to introduction of watershed-based technologies, as they may not require group action to implement. However, this means that special institutional arrangements will have to be made to ensure participation by smaller farmers from the start. If (in the absence of group action and organization) the rate of natural adoption on larger farms is higher than on smaller farms, the result may have a good demonstration value to smaller farmers and provide them with the urge to come together to harness and apportion the benefits and costs. More data are required on the spatial distribution of landholdings across farm-size groups before it can be determined if larger farms are more consolidated.

In the two Sholapur villages, farmers have much less animal-draft power per unit area than elsewhere due to the occurrence of 2 to 3 years of drought which depleted bullock numbers (Table 78). This has resulted in a large proportion of farmers leasing out their land and resorting to farm and non-farm employment, which now is their major source of income. Some members of these households outmigrate to towns and /or irrigated areas on a temporary or seasonal basis. The dynamic nature of such land-tenure and labor-employment activities in response to seasonal and climatic factors suggests some potential constraints to group-action arrangements and organizational forms

**Table 78. Resource bases by farm-size group in six SAT villages in India (1 July 1975).**

| Village and farm-size group[a] | Operational area of farm size group | Average size of holding | Irrigable area | Bullocks | Area per bullock | Family workers | Area per worker | Value of farm equipment[b] | |
|---|---|---|---|---|---|---|---|---|---|
| | (ha) | (ha) | (%) | (no/10 ha) | (ha) | (no/10 ha) | (ha) | (Rs/farm) | (Rs/ha) |
| 1. Aurepalle, Mahbubnagar District (red soil): | | | | | | | | | |
| Small | 0.2-1.2 | 0.8 | 4.8 | 5 | 2.1 | 47 | 0.2 | 186 | 226 |
| Medium | 1.3-3.2 | 2.3 | 10.8 | 3 | 2.8 | 18 | 0.5 | 902 | 401 |
| Large | > 3.2 | 4.9 | 13.9 | 4 | 2.8 | 4 | 2.8 | 3657 | 317 |
| All farms | — | 2.6 | 13.0 | 4 | 2.7 | 8 | 1.3 | 1582 | 325 |
| 2. Dokur, Mahbubnagar District (red soil): | | | | | | | | | |
| Small | 0.2-0.8 | 0.6 | 75.3 | 3 | 3.0 | 31 | 0.3 | 493 | 813 |
| Medium | 0.9-2.1 | 1.7 | 53.3 | 4 | 2.9 | 19 | 0.5 | 872 | 507 |
| Large | > 2.1 | 2.4 | 39.3 | 6 | 1.6 | 8 | 1.3 | 2845 | 601 |
| All farms | — | 1.6 | 38.3 | 5 | 1.9 | 12 | 0.8 | 1403 | 596 |
| 3. Shirapur, Sholapur District (deep black soil): | | | | | | | | | |
| Small | 0.2-2.0 | 1.4 | 10.3 | 4 | 2.8 | 20 | 0.5 | 321 | 231 |
| Medium | 2.1-5.3 | 4.5 | 5.4 | 2 | 6.0 | 10 | 1.0 | 785 | 163 |
| Large | > 5.3 | 7.3 | 10.2 | 2 | 2.7 | 5 | 2.1 | 1656 | 227 |
| All farms | — | 4.5 | 10.1 | 2 | 4.5 | 8 | 1.2 | 787 | 175 |
| 4. Kalman, Sholapur District (deep & medium black soil): | | | | | | | | | |
| Small | 0.2-3.6 | 2.9 | 11.4 | 4 | 2.9 | 12 | 0.9 | 256 | 90 |
| Medium | 3.7-8.5 | 6.5 | 7.8 | 1 | 8.1 | 4 | 1.6 | 947 | 146 |
| Large | > 8.5 | 8.0 | 11.1 | 2 | 6.2 | 5 | 3.0 | 1692 | 129 |
| All farms | — | 5.8 | 11.0 | 2 | 5.8 | 4 | 2.3 | 985 | 129 |
| 5. Kinkheda, Akola District (medium black soil): | | | | | | | | | |
| Small | 0.2-2.0 | 2.4 | 1.7 | 4 | 2.6 | 11 | 0.9 | 198 | 85 |
| Medium | 2.1-4.5 | 4.3 | 3.8 | 2 | 4.1 | 7 | 1.4 | 395 | 93 |
| Large | > 4.5 | 6.4 | 1.3 | 3 | 4.1 | 3 | 3.4 | 767 | 61 |
| All farms | — | 4.3 | 2.1 | 4 | 3.9 | 5 | 2.1 | 454 | 71 |
| 6. Kanzara, Akola district (medium black soil): | | | | | | | | | |
| Small | 0.2-1.8 | 1.4 | 17.0 | 1 | 14.2 | 33 | 0.3 | 282 | 199 |
| Medium | 1.9-5.3 | 3.9 | 2.0 | 2 | 4.4 | 15 | 0.7 | 316 | 80 |
| Large | > 5.3 | 5.8 | 4.5 | 3 | 3.5 | 5 | 2.3 | 120 | 132 |
| All farms | — | 3.7 | 4.5 | 3 | 3.9 | 9 | 1.1 | 724 | 125 |

[a] Mahbubnagar district, in Andhra Pradesh, averages 71 cm rainfall annually. Sholapur and Akola districts, in Maharashtra, average 69 and 82 cm annual rainfall, respectively. Village-Level Studies have been conducted in these villages since May 1975. The number of farms in each group in each village is 10.

[b] Farm and irrigation machinery, hand tools, other farm implements.

which may be required to implement watershed-based technology. .Such group organizations must allow flexible participation not only between seasons but within them.

The relative shortage of draft power, particularly in the Sholapur villages, as well as seasonal labor shortages, act as bottlenecks to timely agricultural operations. For example, the desirability of post-harvest cultivation practices for moisture conservation and weed control are well known to farmers. But as bullock-power is in short supply and hiring rates are hence high, not more than 25 percent of farmers undertake these operations within 4 weeks after the crop harvest. As the resource situation eases, more farmers begin cultivation, many of them only harrowing rather than ploughing so as to complete the tasks in time. Virtually all farmers have their land cultivated prior to the onset of the rainy season, which appears to be a desirable practice from preliminary research by the Farming Systems scientists at ICRISAT.

The number of family workers per 100 hectares among villages varies from 42 to 123 on larger farms; land per worker varies from 2.3 ha to less than 1 ha. On small farms, land per worker varies from less than one-fourth ha to more than 1 hectare. Farmers with such small areas of land have difficulty sustaining themselves on farming alone. As a result, the number of different income sources is inversely related to the size of landholdings.

Peak-wage rates at certain times—such as groundnut harvesting—were three to four times higher than at more lean periods. In neighboring irrigated areas, wage rates can be four to five times higher than in rainfed areas. These are the reasons why small farmers in particular may not care for their crops as well as do larger farmers. Instead of remaining in the village, they outmigrate for work at the higher wage rates, presumably in the belief that the return from better care of their own crops is less assured and more variable than the return from wage employment.

On three Maharashtra villages with medium-deep black soils, 84 to 89 percent of the farms are completely bunded. The fourth village has deeper black soils and more than 55 percent of its farms have no bunding at all. In the red-soil villages in Andhra Pradesh, there is almost no bunding.

Wells and tanks are the primary irrigation sources in the six villages. In three of the four Maharashtra villages, 50 percent of the wells are out of use. In the Andhra Pradesh villages, the figure was much less–20 percent. Inadequate depth and lack of finance for deepening and purchase of lifting devices were the primary reasons given for non-use. The average investment in unused wells (1974-1975 values) was Rs 7 500; a substantial figure compared to the resource position of the average farmer. The additional capital requirement appears to be the major constraint to exploitation of groundwater.

**Risk and Uncertainty in SAT Agriculture**

The overall goal of this project is to assess the implications of high instability of agricultural production in the SAT. Information derived from the project will facilitate (i) the design of technologies by the Crop Improvement and Farming Systems programs at ICRISAT, (ii) the provision of agro-support services, such as input supplies and credit, and (iii) general economic policies such as investment strategies and relief policies, towards the SAT areas.

On the basis of data gathered in previous studies conducted in Rajasthan, ICRISAT researchers found that farmers' adjustment mechanisms to fluctuations in production are well-developed and aimed primarily at maintaining productive assets through scarcity periods. In drought situations, farmers will first respond by reducing consumption, then by use or disposal of existing stocks and inventories, then by sale and mortgage of non-productive assets, and only in the last resort by sale of productive assets or migration.

This knowledge is contrary to some recent suggestions that migration and sale of assets are normal adjustment mechanisms at the beginning of distress and that only falling consumption levels are good signals of true distress. Our evidence suggests that relief measures which are not applied until productive assets are sold or migration occurs come too late. Efficient government intervention should aim at supporting the farmer's adjustment mechanisms and fit into his adjustment sequence.

### Comparison of Human, Animal, and Mechanical Power Sources in the SAT

This project is designed to complement activities of the Farming Systems program in the area of bullock-powered equipment. It is primarily aimed at a comparative evaluation of the potential of various types of equipment and forms of mechanical power in different areas of the SAT.

It was found that agricultural engineering departments of universities and research institutions in the SAT and elsewhere have been only a minor source of mechanical inventions, or even of minor design changes which aim to adapt existing designs to particular locations. Design innovations have always come from private enterprises in the agricultural-machinery industry. Agricultural mechanization is usually not constrained by the lack of design for machines, but rather by the lack of demand due to low wage rates, lack of complementary biological technology, small farm size, and scarcity of capital and credit.

A review of some of the literature on the availability of bullock draft power in Indian agriculture reveals that bullock power on Indian farms is relatively underutilized. Data from various studies show that the total number of 8-hour days worked by bullock pairs varies between 45 and 165 per year. This suggests an underutilization of between 17 to 68 percent, assuming a 200-day work-year. The extent of underutilization did not seem to be systematically related to farm size or extent of irrigation. The intraseasonal pattern of utilization of bullock power seemed to be more uniform in irrigated areas, which had more multiple cropping than did rainfed areas. This has implications for development of new technologies. Peak periods were either in June and July or December and January for rainy season areas, and October and November for postrainy season areas.

These findings, made from the preliminary literature review, remain to be confirmed from data generated in the village-level studies.

### Economics of Prospective Technologies for the SAT

The primary aim is to carry out economic analyses of experiments conducted at ICRISAT Center and elsewhere on small plots and on larger watersheds with the view of identifying promising technologies and practices and to guide decisions about future experiments.

A complete economic analysis of the operational-scale watershed experiments for 1973-1974 and 1974-1975 at ICRISAT Center has been completed. Using extensive crop-fertilizer response data, mostly from experiments conducted in farmers' fields in India, an appraisal of the "package-of-practices" approach to adoption of HYV (high-yielding varieties) of food-grain crops was also completed.

On the basis of limited evidence, closer examination of the current emphasis in research and extension on the "package-of-practices" approach is warranted. If the aim is increased levels of adoption of new technologies, the analysis suggests that parts of the package alone can have a significant contribution, particularly for capital-scarce small farmers. With this in mind, it may be preferable to direct research and extension efforts towards provision of "ranges of input options," rather than a single "package of input practices."

In another part of this project, multiple-regression equations were successfully employed to measure the determinants of runoff on small watersheds at ICRISAT Center and at Ludhiana. More than 90 percent of the variation in runoff was explained by rainfall, antecedent rainfall, land slope, vegetative cover, type of cultivation, and rainfall intensity (Table 79).

## Table 79. Determinants[a] of runoff from small watersheds at ICRISAT Center and at Ludhiana, 1973 and 1974.

| Site and Year | Rainfall squared (mm/day)² | Rainfall squared (mm/day)² x Cumulative Rainfall (mm) | Rainfall squared (mm/day)² x Slope (%) | Rainfall squared (mm/day)² x Seedbed Conformation | Rainfall squared (mm/day)² x Vegetative cover (weeks) | Rainfall squared (mm/day)² x Rainfall intensity (mm/hour) | Year dummy | |
|---|---|---|---|---|---|---|---|---|
| | Explanatory variables[b] | | | | | | | |
| ICRISAT Center (Patancheru, Andhra Pradesh) | | | | | | | | |
| 1973 | .00377** (19.04)[c] | | | | | | | 0.48 |
| 1973 | −.0031** (4.39) | .000046** (6.86) | .002606** (7.57) | .00356** (3.05) | −.00016** (3.69) | .000027** | | 0.62 |
| 1974 | .00573** (28.65) | | | | | | | 0.85 |
| 1974 | .00081 (0.45) | .000012 (0.75) | .00244* (2.01) | −.00099 (0.85) | .00011* (3.79) | .00015** (5.00) | | 0.92 |
| 1973/1974 | .00619** (4.87) | | | | | | −2.7905** (7.75) | 0.85 |
| 1973/1974 | .00356** (4.70) | .000032** (4.00) | .00144** (3.03) | −.001* (1.96) | .00013* (7.65) | .000011 (1.00) | −2.1330** (6.36) | 0.88 |
| Ludhiana, Punjab | | | | | | | | |
| 1973 | .01387** (52.64) | | | | | | | 0.93 |
| 1973 | .00628** (13.95) | −.00012** (24.00) | .00018 (0.95) | —[d] | .00019** (5.76) | .00058** (27.62) | | 0.99 |

[a] The dependent variable in all cases is runoff expressed in mm/day. These results are preliminary.

[b] Rainfall is measured in mm/day. Cumulative rainfall is expressed as total rainfall (mm) falling on the five days preceding observation. Slope is in percentage. Seedbed conformation is given the value of 0 for flat and the value of 1 for ridge and furrow. Vegetative cover is expressed as the number of weeks following planting. Rainfall intensity is expressed as average mm/hour. The year dummy takes the value 1 for 1974 and the value 0 for 1973.

[c] Figures in parentheses are 't' values. * denotes significance at the 5-percent probability level. ** significance at the 1-percent probability level.

[d] Ludhiana data relate to flat planting.

**Table 80. Measurement and relevance of selected evident seed characteristics of pulses[a] and cereals[b].**

| Characteristic | Laboratory Measurement | Traders' or consumers' measurements or evaluations | Relevance |
|---|---|---|---|
| Weight | 100-seed weight (g) | Observation of seed size at time of transaction | Large seeds, up to a point, are generally regarded as being superior to small seeds. |
| Density | 10 g dry pulse seed in 50 ml water; 5 g dry cereal seed in 20 ml water | Estimate of seed density by hefting at time of transaction. | A high density indicates more substance in a given volume of grain, which may or may not be preferable. |
| Water uptake | Change in weight (g) and volume (ml) after 24 hours of soaking; g/ml ratio | Observation of swelling while preparing dhal (pulses) and water uptake while preparing chapaties (cereals). | At time of purchase, this characteristic may be evaluated only through inference from other qualities. It appears to be related to cooking qualities, and therefore is likely to be relevant as a factor influencing demand.[c] |
| Color | Percentage of grains of standard colors | Observation at time of transaction. | Seed color may directly affect the flavor of grain, and may indirectly permit inferences regarding other seed qualities. |

[a] Chickpea, pigeonpea

[b] Sorghum, pearl millet

[c] von Oppen, M., "Measurement of pigeonpea seed characteristics." ICRISAT, Hyderabad, India, Apr 1975 (mimeo)

**History and Economics of Existing Tank Irrigation in India**

In India, the technique of storing runoff water in so-called tanks for irrigation is an old and widely established practice. In 1969-1970, about 4.5 million hectares—15 percent of India's net irrigated area—were irrigated by tanks.

Results of the survey of 33 tanks in Andhra Pradesh and Maharashtra indicate that water-management practices differ regionally. In Rayalaseema, a red-soil low and bimodal rainfall area, only one crop is taken after the tanks are full. In Telangana, a red-soil unimodal and higher rainfall area, the tanks are left open and start flowing from the beginning of and throughout the rainy season to grow a first crop. Whatever water is left afterwards is allocated to a corresponding area for a second crop. In Maharashtra, the irrigation water is distributed after written applications have been received. In Rayalaseema and in Telangana, water rates are levied uniformly per irrigated acre. In Maharashtra, water rates vary, dependent upon the crop. In the tank-irrigated areas of Rayalaseema, paddy is drilled (as a rainfed crop) early in some areas before irrigation is given and sometimes groundnuts are grown. In Telangana, transplanted paddy is the only tank-irrigated crop. In Maharashtra, a variety of crops—such as sorghum, sugarcane, groundnuts, paddy or ragi—is found under tank irrigation.

At this point, it can be concluded that improvements to the existing tank-irrigation systems would require not only technical changes in the tank design, but might involve basic readjustments of the institutional and legal practices for water-pricing and management.

## Marketing Economics

Research projects in marketing economics are primarily addressed to quantifying market-imposed constraints on the development and adoption of new technologies. Results of one of the four projects underway in this field are discussed below.

**Evaluation of Relevant Economic Characteristics of Legumes and Cereals in SAT**

During the past year, preliminary surveys were conducted in six wholesale markets in and around Hyderabad. Samples of pigeonpea, sorghum, chickpea, and pearl millet were collected. The samples were tested for a number of relevant characteristics, such as 100-seed weight, seed density, water uptake during soaking, and color mix (Table 80).

Preliminary analysis of the data generated for pigeonpea indicates that between 60 and 70 percent of the variation in price can be explained by variation in selected quality characteristics. Hundred-seed weight, percentage of white seeds, and volume of dry seed were found to have a significant positive influence on price, while proportion of non-white seeds and volume of soaked seeds were found to depress price. This finding is based only on data collected from markets near Hyderabad; in other regions, consumers' preferences are likely to differ.

For chickpea, results from two Andhra Pradesh markets show that 100-seed weight consistently explained price variation. However, color preferences differed significantly between the two markets reflecting the existence of regional differences in consumer preferences.

# Cooperative Programs

The development of strong programs of collaboration and assistance with research centers in the SAT countries of the world was early recognized by ICRISAT as one of its most-important responsibilities. As rapidly as research programs were developed and plant material and technological information became available at ICRISAT, steps were taken to initiate cooperative programs with a number of such centers. In the early stages, cooperation was limited to provision and exchange of germplasm of the five ICRISAT crops and to short-term consultancies from senior staff members. As these programs evolved, more-formal arrangements for increased and closer collaboration were undertaken in several countries, others are under active consideration and may be implemented shortly.

## West African Cooperative Project

A project for a cooperative program of research and training for the improvement of sorghum and millet in the Sahelian-Sudanian zone of West Africa was initiated in January 1975 with the signing of an agreement with the UNDP under the title "ICRISAT West African Cooperative Program for the Improvement of Sorghum and Millet." The major objectives of the program are to cooperate with and assist in strengthening the West African research and production programs for development of improved varieties of sorghum and millet and for defining production practices and techniques and systems of farming and land and water management which will lead to increased and more-reliable production of these crops and an improvement in their food quality. Providing training for candidates from these countries is also of vital importance. The focal point is to strengthen the national programs of the twelve countries of the region (Senegal, Gambia, Mauritania, Mali, Togo, Benin, Ghana, Upper Volta, Niger, Nigeria, Chad, and Cameroon) with teams of scientists located in Samaru (Nigeria), Bambey (Senegal), Kamboinse (Upper Volta), and at a location to be selected in Niger. Through close collaboration with the accelerated-crop-production officers (formerly field-trials officers) in these nations, links are to be established with their extension and field-application programs.

In the first year of operation, 1975, the program began to slowly gain momentum as personnel for the senior positions were identified. An office for the Project Leader for the West African Program was established in Dakar. A plant breeder for sorghum and secondarily for millet joined duty in Upper Volta, and has completed a full season of testing and selection in plot trials of these crops at a number of locations. He has also initiated an ambitious breeding program on sorghum. An agronomist was appointed temporarily to Senegal.

In early 1976, a millet breeder was posted to Nigeria and a plant pathologist to Upper Volta. An agronomist joined, on a short-term basis, the research team in Upper Volta. Expansion in staffing (with five additional scientists to be recruited) is planned for 1976. The scientists will be phased into the programs of the cooperating nations as rapidly as they can be selected, and as local logistic support permits. ICRISAT scientists will work closely with scientists of the host countries and in full cooperation with other agencies, such as OAU/STRC, French Government/IRAT/ORSTOM, UNDP/FAO, USAID, ODA/UK, IDRC, and the European Community who are already contributing substantially in the region to support activities closely related to the objectives of this project.

An agronomist funded by Ford Foundation and USAID has been posted in Mali. It is anticipated that this will represent the first of a number of extensions to the UNDP-sponsored West African Project.

The project has been moving steadily forward. There has been a free exchange of seeds of sorghum and millet between ICRISAT and the cooperating nations, and in a number of countries multilocation testing for adaptability of improved strains has been undertaken as part of the regional research program on crop improvement. At the designated centers, research teams have initiated ambitious breeding programs in close collaboration with national programs, while at the same time developing the broader regional role they must play. Senior scientists from ICRISAT Center, acting as consultants, have made frequent visits to many of the countries of the region.

Training of indigenous scientists and technicians for the region is now getting underway, utilizing ICRISAT's temporary facilities in Hyderabad. Thus far, a total of 32 candidates from West Africa have received the ICRISAT training course in breeding, production agronomy, and farming systems. They have come from Senegal, Mali, Upper Volta, Niger, Nigeria, and Chad. Special arrangements have been made to provide trainees from French-speaking countries with an intensive English-language course prior to enrolling in the in-service training program. The accommodations problem is expected to be solved upon completion of dormitories and classrooms at ICRISAT Center.

In 1977, the project is expected to reach its full impact. Recruitment of the remaining staff will be completed, and the research teams will have experience. The exchange and testing of materials within and between countries and ICRISAT will be fully operational, as will be the coordinated exchange of information regarding the performance of the various plant materials and their potential value to specific locations or to wider regions. Training will also expand in 1977. Recognizing the vital and lasting importance that training provides to the overall success of the project, ICRISAT encourages countries within the region to select potential candidates for training and enroll them as soon as it is expedient to do so. It is anticipated that 30 to 40 trainees from West Africa may be enrolled in the various options in 1977.

In January 1976, an important conference sponsored jointly by the OAU/STRC and CEAO was held in Upper Volta on "Semi-Arid Food Grain Research and Development in Africa (SAFGRAD)." There was general agreement that expansion of the present program, designed to more fully meet the research requirements of the region, is essential. A working paper outlining a greatly expanded ICRISAT and IITA role for the region was endorsed. The proposal also projects greatly increased budget requirements, and although donor support for a substantial amount of the total funding required for the project was not yet identified, general optimism that the program may be initiated, at least in part, in 1977 was prevalent.

**East African Cooperative Programs**

A proposal for a sorghum and millet improvement program for Tanzania, to be conducted in collaboration with the Government of Tanzania, IITA, and USAID, is under active discussion. Tanzania has expressed renewed interest in increasing its production of sorghum and millet, and a major objective of the project would be to develop varieties and methods of culture which would give improved and more-stable yields, better quality, and greater dependability of harvest. Particular attention will be paid to varieties of short to medium duration, short to medium height, good grain quality, drought tolerance, and resistance to important pests and diseases of the area—including *Striga*, birds, shoot fly, and stem borer. The project would emphasize testing under a variety of ecological conditions and working in close association with local scientists. The development of improved varieties of pigeonpea also has a high priority. ICRISAT scientists have visited the research stations and have established informal links with local program leaders. They have provided promising seed materials for screening and selections.

Kenya has also expressed renewed interest in increasing production of sorghum, millet, and pigeonpea in its low-rainfall medium-potential areas. ICRISAT scientists have been in consultation with the Kenya officials and scientists to define the cooperative role that might be most appropriate for ICRISAT. This has led to a free exchange of germplasm of the various crops and ICRISAT has supplied segregating and advanced lines of sorghum, millet, and pigeonpea for testing and selection in Kenya.

There remains a strong desire on the part of both ICRISAT and Ethiopia to enter into a formal cooperative program to be headquartered at the College of Agriculture, Haile Selassi I University, Alemaya, which is also the leadership center for the national program of sorghum improvement. The project is visualized by ICRISAT as an extension of (and complementary to) the current IDRC project in Ethiopia. Due in part to the ICRISAT recruitment pattern, which has deferred the filling of a number of positions until 1977, the organization of this program has not moved as rapidly as had been anticipated initially. At present, however, there is an active exchange of seeds of sorghum and chickpea and on-site visits by ICRISAT scientists.

### South American Cooperative Program

**Brazil.** ICRISAT scientists made four preliminary visits to Brazil to study opportunities for cooperation in the northeastern SAT region of that country. Brazil has undergone significant and far-reaching reorganization and redirection of its agricultural research and extension programs, and has indicated an active interest in developing a cooperative program on sorghum and millet improvement with ICRISAT. The Ford Foundation is presently providing financial assistance to the national program on sorghum and millet breeding, and has made funds available to ICRISAT to provide backup support. This will take the form of providing germplasm and advanced lines of sorghum and millet for testing and improvement, short-term consultancies by ICRISAT senior scientists, training of local scientists, and the sponsoring of workshops and conferences to discuss major breeding and production problems. It is envisioned that the ICRISAT's present involvement may be the forerunner of a more-comprehensive cooperative program.

### Asian Cooperative Programs

Thailand became a contributor to the ICRISAT cooperative program in 1975 as a first step to strengthen collaboration already underway in the exchange of germplasm and advanced lines of sorghum. ICRISAT will also continue to provide consultancies by its senior scientists, along with other back-up support within its present means.

ICRISAT scientists continued to supply nurseries of appropriate crops to Pakistan, Bangladesh, and Sri Lanka for selection of adapted types and continued to visit research centers in an advisory capacity. A formal working agreement between ICRISAT and Pakistan has been discussed and is under active consideration by both parties.

**India.** India, the host country for ICRISAT, has continued to provide invaluable support—at both the national and the state levels. The 1394-hectare site of unparalleled quality was provided for ICRISAT Center, and the people of two villages previously located thereon were resettled elsewhere by state and district authorities. The national Plant Protection Training Institute, located nearby, has established procedures for quarantine inspection of incoming and outgoing seed for the Institute's research work and its genetic-resources collection programs, and has handled large numbers of seed lots expeditiously.

The national coordinated research projects on sorghum, millets, pulses, and oilseeds, along with some of the state institutions, have assembled some of the largest and most-extensive collections of cultivars and genetic stocks of the basic crops with which the Institute is concerned. They were generous in sharing these with the Institute; the sharing formed a large part of ICRISAT's basic germplasm resource for initiating its crop-improvement programs and enabled the Institute to move forward very rapidly in this field.

Informal and formal cooperative arrangements are being established with the All-India Coordinated Programs on sorghum, millets, pulses, oilseeds, and dryland agriculture supported by the Indian Council of Agricultural

Research and carried out in cooperation with various agricultural universities and state and central government institutions. Visits of Indian scientists to ICRISAT Center and of ICRISAT scientists to the research institutions, along with participation of both groups in workshops organized by ICRISAT and those organized by the All-India projects, is increasing as ICRISAT's growing program and staff talent permit. ICRISAT has organized specially selected group visits of Indian scientists to (i) sorghum (ii) millet (iii) pigeonpea (iv) chickpea, and (v) farming systems field experiments. Generally field visits of 2 to 3 days are organized for which a selected group of 30 to 40 scientists engaged in research on a particular crop or subject-matter area are invited. After seeing the experiments, these scientists are encouraged to select material which may be of interest to them. This enables them to take the breeding material and promising lines for use in their breeding programs. This type of seed transfer stimulates and accelerates crop research programs all over the country.

These relationships provide an extremely valuable means for gaining insights into the problems and needs of rainfed agriculture on the sub-continent. Counsel of the Institute's program development and priorities, and suggestions of avenues through which might be put into practice the improvements in varieties, genetic materials, and technology developed by the Institute has been most valuable.

Cooperative relationships are being established with several of the state agricultural universities. Those of Andhra Pradesh and Maharashtra are cooperating in village-level studies aimed at identifying and understanding the constraints and problems to be met in application of changes and improvements in production technology. Additionally, arrangements are being made with some of these universities for assistance with the growing of crop nurseries under environments important to the semi-arid tropics, but different from those found at ICRISAT Center.

The Andhra Pradesh Agricultural University will provide arrangements for postgraduate degree programs for cooperating scientists; the thesis-research programs will be carried out under the direction of ICRISAT scientists. The University of Agricultural Sciences, Bangalore, is providing excellent facilities at its Dharwar center for research on downy mildew of sorghum. The agricultural university at Akola is providing facilities for collaborative work on *Striga*; the J.N. Krishi Vishwa Vidyalaya (agricultural university) at Jabalpur for work on leaf diseases of sorghum at Indore and late-maturing pigeonpea at Gwalior. The Haryana Agricultural University, Hissar, is providing excellent cooperation for research on chickpea and pearl millet while the Tamil Nadu Agricultural University is making facilities available for off-season research on sorghum and millets at Bhavanisagar. The Himachal Pradesh Government provided land facilities in the Lahaul valley for advancing chickpea generations. Many agricultural institutes and research stations of coordinated projects are extending their facilities for cooperative trials on screening for disease resistance and suitability of a genotype for different environments.

### Other Organizations

ICRISAT recognizes a great backup resource in the scientific laboratories and institutions of its host country—India—and of the various nations represented in the Consultative Group. These will be cultivated and developed as they are identified and mutual interests and opportunities can be matched. Among those of particular interest are the sorghum protein-quality program at Purdue University; the conversion and disease-resistance programs with sorghum at Puerto Rico and at Texas A and M University, the program on physiology of stress at the University of Nebraska; the drought-stress program at Saskatoon; the projects on stimulants to germination of *Striga* and orobanche at Sussex and the Weed Research Organization of the UK; physiological studies on tropical-plant responses to closely controlled environmental conditions in the phytotrons at Reading, England, and the CSIRO, Australia; programs on water relations and on legume improvement at Cambridge; the root-development studies at Letcombe Laboratories, UK; nitrogen-fixation and rhizobium cultures for tropical legumes by the CSIRO, Australia, the Taximetrics Laboratory of the University of Colorado, and many others. Generally, the major financing of these projects will come from sources outside ICRISAT, but their results will be of considerable importance to ICRISAT's program. Through joint collaboration, the relevance of such projects to the semi-arid tropics can be sharpened; facilities and scientific talent of such institutions can complement those of ICRISAT and relieve it of certain segments of work; ICRISAT can in turn provide needed facilities and environments for study of the field aspects of the problems under investigation. Other international institutes have already made considerable progress in developing this type of cooperation, and ICRISAT considers it to be an important avenue in development.

# Fellowships and Training

ICRISAT's training program got underway in 1974 with the enrollment of four Nigerians in a production-technology course in sorghum and pearl millet. The program was expanded with the appointment of a Training Officer and an Associate Training Officer in the spring of 1975. The programs can be broadly described as being of three categories:

**Research fellows:** Research fellows hold M.Sc. or Ph.D. degrees and work with Institute scientists on specific research programs for one or two years.

**Research scholars:** Research Scholars are students who are working toward the M.Sc. or Ph.D. degree in a university; the thesis research is performed under the supervision of ICRISAT scientists.

**In-service trainees:** Scientists, workers, managers, and administrators who wish to develop and practice skills for the improvement and stabilization of agriculture in SAT areas.

In-service training courses vary from a few weeks to a few months in length. They are offered to degree and non-degree personnel desiring practical skill development in methods of applying technology and managing resources to improve conditions for small SAT farmers with limited means. Courses stress either crop production or crop improvement, commensurate with specific needs in the home country of the trainee. Programs are developed and conducted with the aid of ICRISAT scientists.

In 1975, arrangements for research programs for five degree course candidates enrolled at Andhra Pradesh Agricultural University were finalized.

Forty-six persons completed training courses (Table 1).

Persons completing ICRISAT's 1976 in-service training programs include—*Bangladesh* (crop improvement), A.B.M. Salahuddin; *India* (crop improvement), N.N. Kolte and R.S. Wadhokar; *Nigeria* (crop production), A.M. Zurmi, Umaru Faragai, Garba G. Gusau, C.I. Akamiro, Samaila Agabus, T.B. Maliki Daniel, Othman Kyari, and C. Sale Samban.

Persons completing short-term courses include—*India* (agricultural engineering), K.L. Ganju, J.P. Sharma, S.A. Quadri, and Surender Singh; (pearl millet improvement), Sain Dass; *India-/Switzerland* (farming systems), Otto Weilenmann; *Niger* (seed production), Willie Russell; *Upper Volta* (entomology), S.M. Bonzi; *West Germany* (cultivation in the SAT), Miss B. Zopfy and N. Didden.

In 1976, 6-month courses in sorghum and millet improvement began for two trainees each from Senegal, Upper Volta, Mali, and Chad, and four trainees from Niger. Prior to beginning the course, these trainees completed 2 months of intensive study of the English language at the Central Institute of English and Foreign Languages in Hyderabad, Six trainees from Nigeria's National Accelerated Food

*Training has a high priority at ICRISAT, and its program is constantly expanding. In addition to inservice training programs, programs are planned for graduate and post-graduate work. Special emphasis is given to needs of developing nations. Inservice training focuses on crop improvement and crop production.*

Production Project began a 6-month course in sorghum and millet production.

It is planned that ICRISAT's in-service training programs in crop production and crop improvement will be scheduled as in Table II.

**Training Activities in Farming Systems**

Training activities by farming-systems staff during the 1975-1976 year included the following: lectures and training in various facets of field research, initiation of a post-graduate program for three students in cooperation with APAU, a week-long intensive training course for officers in the Drought Prone Area Program (DPAP);[1] a 2-day training program for administrators from DPAP; and preparation of a slide set and its distribution to DPAP, several agricultural universities, and other groups.

A 6-month in-service training course in farming systems is being planned. The broad areas covered in this training program will emphasize land and water management and engineering, agronomy, soil science, and socio-economics. In addition to training programs at ICRISAT Center, it is envisioned that training programs will be conducted by cooperative research

[1]The training program was jointly organized and conducted by the All India Coordinated Research Project for Dryland Agriculture, the Central Soil and Water Conservation Research Training Institute, DPAP and ICRISAT.

**Table I**

| Program | Number of Trainees | Country | Length |
|---|---|---|---|
| **Research Scholar (APAU):** | | | |
| Agronomy | 1 | Sudan | Continuing |
| Soil chemistry and pathology | 4 | India | Continuing |
| **Short-term courses:** | | | |
| Production technology (sorghum and pearl millet) | 8 | Nigeria | 6 months |
| | 2 | West Germany | 3 weeks |
| | 1 | Switzerland (working in India) | 4 weeks |
| Sorghum Breeding | 2 | India | 6 months |
| | 1 | Bangladesh | 6 months |
| Agricultural Engineering | 3 | India | 2 months |
| Agricultural Economics (field investigations) | 6 | India | 3 weeks |
| Entomology | 1 | Upper Volta | 8 weeks |
| Land and water management (for Drought Prone Area Programme district agricultural officers) | 16 | India | 1 week |
| Sorghum and pearl millet (with emphasis on seed production) | 1 | USA/Niger | 4 weeks |

**Table II**

| | | |
|---|---|---|
| **Crop production—** | | |
| Sorghum, pearl millet, groundnut | (6 months) | May to Nov. |
| Pigeonpea | (10 months) | May to Mar. |
| Chickpea | (6 months) | Sep. to Feb.-Mar. |
| Farming Systems | (6 months) | May to Nov. |
| **Crop improvement—** | | |
| Sorghum, pearl millet, groundnut | (6 months) | May to Nov. |
| Sorghum, pearl millet | (6 months) | Sep. to Mar. |
| Pigeonpea | (6 months) | Oct. to Apr. |
| | (7 months) | Sep. to Mar. |
| | (10 months) | Jun. to Mar. |
| Chickpea | (6 months) | Sep. to Feb.-Mar. |

programs at selected bench-mark locations throughout the SAT. The major training activity at these locations would be carried out by national-program scientists supplemented, where necessary, by on-station ICRISAT staff and/or visiting scientists.

## Workshops, Conferences, and Seminars

Exchange of information for the transfer of technology and cooperative research is essential and workshops and conferences provide an effective channel for this purpose. During 1975-1976 a number of international workshops and consultants' meetings were held.

### Sorghum Program—A Review by International Consultants

In case of sorghum, it was considered desirable to call a meeting of few well-known sorghum scientists for critical review of the sorghum research program. The meeting was held 15-18 April 1975. Eight consultants were invited. ICRISAT's sorghum research philosophy and approach was critically reviewed. The recommendations of the consultants' meeting helped ICRISAT scientists make appropriate changes in the research program.

### Consultants' Group Meetings on Downy Mildew and Ergot of Pearl Millet

In view of the seriousness of the downy mildew of pearl millet, a consultants' meeting was held 1-3 October 1975. Twelve plant pathologists with specific knowledge of downy mildew participated. Y.L. Nene and S.D. Singh, ICRISAT plant pathologists, prepared a comprehensive review paper which formed the basis of the discussion. The recommendations of this meeting brought into sharp focus the complex problem of the seed-borne nature of downy mildew in pearl millet and suggested critical experimentation. It also reviewed the position of research in ergot and drew attention to smut and other diseases of pearl millet. The recommendations of the consultants' group stimulated intensive research on downy mildew, which ultimately led to the development of a technique for getting rid of the pathogen.

### International Seminar on Uses of Soil Survey

On the suggestion of Dr. L.D. Swindale, Associate Director, Research, University of Hawaii (now Director of ICRISAT), who was the coordinator of research on soil survey and classification of bench-mark soils in tropical countries, ICRISAT provided the venue for an international conference on soil survey in January 1976. About 80 participants attended. The conference reviewed the application of a comprehensive system of soil classification commonly known as seventh approximation to tropical soils and discussed the international network for bench-mark soil studies in this region. The conference, sponsored by USAID and FAO under contract with the University of Hawaii, emphasized the use of soil classification in planning and implementing agricultural development in the tropics. The proceedings and the papers presented in this conference are being published by the University of Hawaii.

### Seminars

Seminars were a regular feature of the activities of the Institute. Monthly seminars at the Institute's level and weekly seminars at the departmental level were held. Distinguished foreign visitors also gave a number of seminars on topics of interest to ICRISAT. This provided a valuable forum for the exchange of information.

# Germplasm Exchange and Quarantine

Assembly of germplasm from all over the world and distribution of cultivars to cooperating scientists for testing in other countries are primary functions of ICRISAT breeding programs. To prevent the movement of exotic insect pests and diseases across international borders, all seed exchanges were carried out only after quarantine clearance by the Government of India.

The quarantine inspection of sorghum, pearl millet, pigeonpea, chickpea, and groundnut seed material was carried out at India's Central Plant Protection Training Institute, Rajendranagar, Hyderabad. The seed material of other crops essential in the Farming Systems program was cleared at the Plant Introduction Division of Indian Agricultural Research Institute, New Delhi.

### Exchange of Seed-material

A total of 40 862 seed samples from 37countries were imported. Of these, larger quantities came from Australia, Canada, Ethiopia, Kenya, Lebanon, Mexico, Netherlands, Nigeria, Puerto Rico, Senegal, Taiwan, Thailand, and USA. Seed samples totalling 51 531 were sent to collaborators in 71 countries. Bulks of this material went to Bangladesh, Brazil, Burma, Canada, Chile, Columbia, Ethiopia, France, Iran, Israel, Lebanon, Libyan Arab Republic, Mexico, Nigeria, Philippines, Pakistan, Sri Lanka, Sudan, Senegal, Thailand, Tanzania, Turkey, USA, Upper Volta, Uganda, and West Indies. Seed-clearance statistics are presented in Table 81.

### Further Cooperation with Government of India

To avoid delay in the movement of seed material within the country, Government of India was requested to issue instructions to collectors of Customs and Plant Quarantine Stations at all important sea and airports to pass on ICRISAT seed shipments without inspection, which would then be carried out at its Quarantine Unit in the Central Plant Protection Training Institute at Hyderabad. This provision made it possible for seed material to move to Hyderabad quickly for prompt testing.

**Table 81. Seed samples cleared through quarantine, 1975-1976.**

| Seed Material | Samples imported | Samples exported | Total |
|---|---|---|---|
| | (no) | (no) | (no) |
| Sorghum | 28 197 | 24 967 | 53 164 |
| Pearl millet | 885 | 7 320 | 8 205 |
| Pigeonpea | 549 | 2 582 | 3 131 |
| Chickpea | 9 021 | 16 497 | 25 518 |
| Groundnut | 1 658 | 15 | 1 673 |
| Other crops | 552 | 150 | 702 |
| Total | 40 862 | 51 531 | 92 393 |

The importation of seedlings and seeds of groundnuts into India from South America, North America, West Indies, China, and USSR is prohibited under the Destructive Insects and Pests Act. Scientific institutions under the Central and State Governments, however, enjoy an exemption to this provision. Rules were amended in August 1975 to extend this privilege and responsibility to ICRISAT, also.

## Review of Quarantine Arrangements

Quarantine arrangements in case of pearl millet and groundnut were reviewed by an ICAR Committee in December 1975. Downy mildew of pearl millet has become a serious problem in India. An International Consultants' meeting organized by ICRISAT to discuss downy mildew and ergot problem of pearl millet in September 1975 suggested that there is a suspicion that downy mildew of pearl millet may be seed-borne. An intensive cooperative research was suggested to investigate this problem thoroughly. Hence joint studies by ICRISAT and Mysore University are underway to establish definitely whether or not the fungus is internally seed-borne, and to develop technology that will make the seed safe from disease.

## Post-entry Quarantine Inspection

The Quarantine Review Committee of the Government of India has decided that all releases of groundnut and pearl millet should after quarantine clearance be grown first in the Post-entry Quarantine Isolation Area. A total of 490 cultivars of groundnut and 4 cultivars of pearl millet were grown in an isolated plot at ICRISAT Center in consultation with quarantine officers of the Government of India. These cultivars, planted in January 1976, were examined weekly by the quarantine officers of CPPTI and by ICRISAT scientists. Entries showing the slightest doubtful symptoms of exotic diseases were burnt in the incinerator; only healthy cultivars were declared safe for further propagation and experimentation.

Unrooted groundnut cuttings totaling 980 were imported from Reading University, UK, and cleared at the Directorate of Plant Protection Quarantine and Storage, New Delhi, then planted in the ICRISAT nethouse in Hyderabad. The cuttings were examined weekly by CPPTI quarantine officers.

# Computer Services

ICRISAT's computer system, a DECdata system 550 manufactured by Digital Equipment Corporation (DEC) in the United States, consists of a PDP-11/45 central processing unit and a floating-point processor and a memory-management unit. There are 64K 16-bit words of core memory on the system. Peripheral devices include a TU 16 dual-density 9-track tape drive, on 88-million-byte RP04 disk system, a 132-column line printer that will print 300 lines per minute, and six LA36 DECwriter II terminals.

The system is operated as a dedicated timesharing system using the RSTS/E (Research Sharing Time Sharing Extended) operating system. Resources of the system are accessible only through the use of the DECwriter II terminals. The programming language is BASIC-PLUS, an enhanced version of the BASIC language developed at Dartmouth College, New Hampshire, USA.

### Activities

From September through December 1975, ICRISAT's computer operations were conducted at the computer center of ECIL (Electronics Corporation of India). Two main projects—probability distributions for rainfall data from districts in India, and regression analysis of data gathered in economic studies—were performed at ECIL.

While the work at ECIL was going on, the overall computing needs of the ICRISAT staff were further studied, arrangements made for electrical supply and wiring, and staff study of the particulars of the DECdata system conducted. During January 1976, programs acquired from other installations in India and in the United States were installed, tested, and modified to operate in the ICRISAT system. Much effort was devoted to development of the basic integrated statistical library. Since data are stored in disk files, a general file structure was designed and first-version programs for the collection and maintenance of research data files developed. All statistical-analysis programs are designed to access this single-file structure, thus permitting data to be analyzed in whatever ways appropriate without changing its format for each different analysis.

The probability-distribution programs used at ECIL for analyzing rainfall data were converted to run on the ICRISAT equipment in late January. These programs utilize the background batch processor, and data from 40 weather stations have now been analyzed.

During February, instruction in elementary statistics, regression analysis, and design of experiments was presented to ICRISAT scientists and research associates. Course assignments made use of the available statistical analysis routines. This instruction, in addition to strengthening the statistical background of the participants, served as an excellent introduction to the use of the ICRISAT computer and its statistical library. By the end of the month, several research associates were analyzing data from their rainy season harvests.

A file structure was designed to accommodate the village-level studies data collected by the Agricultural Economics unit; the first version of this data-entry and maintenance system for the implementation of this file was completed in mid-May.

A prototype system for generating randomizations for field experiments, printing of labels for seed packets, and printing of the associated field work book was completed in early May. The system provides for the use of a randomized complete-block experimental design and generated a different randomization for each location where the experiment was to be planted. This system was used successfully by sorghum and by pearl millet breeders in their international trials.

### Looking Ahead in Computer Services

Projects scheduled to receive attention during the 1976-1977 year include:

1. Development of an on-line fiscal accounting system and development of a payroll system.

2. Development of an integrated system for performing randomizations for field experiments, printing of labels for seed packets, and the printing of field books.

3. Design of an information storage and retrieval system for germplasm data for the five ICRISAT crops that is compatible with the retrieval system of the Taximetrics Laboratory, University of Colorado.

4. Development of a compact system for the maintenance of mailing lists and the production of address labels.

Other projects which will enter the planning stage during the coming year are library-assistance systems and a system for scheduling ICRISAT's farm field practices.

# Library

Because of limitations in physical facilities, expansion and development of the ICRISAT library was limited during 1975-1976, but every effort was made to provide library services as needed by ICRISAT scientists.

The number of books held by the library nearly doubled during the year (to more than 5 000 volumes), and the number of bound volumes of periodicals increased 140 percent (to 2 000 volumes). Subscriptions to periodicals increased, so that now nearly 400 scientific and professional journals are received.

Use of the library by ICRISAT scientists, as measured by number of documents issued, nearly tripled during the report year. Cooperation with other libraries made it possible to provide 457 documents from other libraries in the Hyderabad area, and 17 documents from distant libraries. On the other hand, the ICRISAT library provided 91 of its documents on loan to other libraries and scientists throughout the world.

A collection of annual reports, especially those of research institutions with missions similar to that of ICRISAT, is especially useful to scientists who wish to avoid duplication of research efforts and to establish contact with workers in similar areas. The collection includes reports from 118 institutions in 24 countries.

The library continued publication of its Monthly List of Additions, Catalog of Periodicals Available, and its Catalog of Theses and Dissertations Available. In addition, it published a union catalog of all theses available at the international agricultural research and training centers.

Plans to make the library a depository of the world literature on the five ICRISAT crops continued. Also, groundwork for establishing an International Information Center on Sorghum and Pearl Millet began; this project will be developed in cooperation with IDRC.

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