ICRISAT ANNUAL REPORT 1976-1977

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International Crops Research Institute for the Semi-Arid Tropics
1—11-256 Begumpet
Hyderabad 500016 (A.P.) India

ICRISAT's Objectives

To serve as world center to improve the genetic potential for grain yield and nutritional qaaiity of sorghum, pearl millet, pigeonpea, chickpea, and groundnut.

To develop farming systems which will help to increase and stabilize agricultural production through better use of natural and human resources in the seasonally dry semi-arid tropics.

To identify socio-economic and other constraints to agricultural development in the semi-arid tropics and to evaluate alternative means of alleviating them through technological and institutional changes.

To assist national and regional research programs through cooperation and support and to contribute further by sponsoring conferences, operating international training programs, and assisting extension activities.

About This Report

This is the fourth annual report published by the International Crops Research Institute for the Semi-Arid Tropics. Printed for worldwide distribution, the report covers ICRISAT's development and activities from 1 June 1976 to 31 May 1977.

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, 1977. *ICRISAT Annual Report 1976-1977,* Hyderabad, India.

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ICRISAT Governing Board

ICRISAT Personnel - May 31, 1977

Administration

R.W. Cummings, Ph.D., director (until 4 Mar 1977)
L.D. Swindale, Ph.D., director (as of 4 Mar 1977)
J.S. Kanwar, Ph.D., associate director
R.C. McGinnis, Ph.D., associate director
S.K. Sahgal, IAS, principal administrator
V. Balasubramanian, executive assistant to the director
S.K. Mukherjee, B.Sc. (Eng'g.), personnel manager
O.P. Shori, B.Sc., B.L., fiscal manager
R. Vaidyanathan, purchase & stores manager
R.G. Rao, records manager
Col. P.W. Curtis (Grad. IMA, Dehradun), security officer
J. Pearson, transport officer (until Feb 1977)
R. Narsing Reddy, transport officer (as of Mar 1977)
S.B.C.M. Rao, B.Com., travel officer
B. Diwakar, Ph.D., scientific liaison officer (visitors service)
N. Rajamani, liaison officer, New Delhi office

Crop Improvement

Cereals

H. Doggett, Ph.D., plant breeder & leader (until Dec 1976)
L.R. House, Ph.D., principal plant breeder (sorghum) (since Nov 1976)
P.K.. Lawrence, Ph.D., assistant plant breeder (sorghum)
D.J. Andrews, B.Sc., (Hons.), D.A.S., D.T.A., principal plant breeder (millets)
B.W. Hare, Ph.D., assistant plant breeder (millets)
J.C. Davies, Ph.D., principal entomologist (leader as of Jan 1977)
J.D. Skinner, Ph.D., assistant entomologist (until Dec 1976)
R.J. Williams, Ph.D., principal pathologist
A.H. Kassam, Ph.D., principal physiologist (until Oct 1976)
F.R. Bidinger, Ph.D., principal physiologist (as of Oct 1976)
Claude Charreau, Ph.D., project leader, West Africa project
A. Lambert, Ph.D., principal plant breeder, Senegal (as of Sep 1976)
R.T. Gahukar, Ph.D., principal entomologist, Senegal (as of Dec 1976)
C M . Pattanayak, Ph.D., principal plant breeder (sorghum), Upper Volta
W.A. Stoop, Ph.D., principal agronomist, Upper Volta (as of Jan 1977)
J.A. Frowd, Ph.D., principal plant pathologist. Upper Volta
J.P. van Staveren, M.Sc., assistant agronomist, Upper Volta (as of Mar 1977)
S.A. Clarke, M.S., field trials officer, Mali
B.B. Singh, Ph.D., principal plant breeder, Niger (as of Apr 1977)
R.P. Jain, Ph.D., principal plant breeder (millets), Sudan (as of Apr 1977)
S.O. Okiror, Ph.D., principal plant breeder, Nigeria
J.V. Majmudar, Ph.D., senior plant breeder (millets)
K.V. Ramaiah, Ph.D., plant breeder (sorghum)
Bholanath Varma, M.Sc, plant breeder (sorghum)
D.S. Murthy, Ph.D., plant breeder (sorghum)
B.L. Agrawal, Ph.D., plant breeder (sorghum), (as of Nov 1976)
S.C. Gupta, Ph.D., plant breeder (millets)
K. Anand Kumar, Ph.D., plant breeder (millets)
K.E. Prasada Rao, M.Sc. (Ag.), botanist (genetic resources)
S. Appa Rao, Ph.D., botanist (genetic resources), (as of Nov 1976)

N. Seetharama, Ph.D., plant physiologist
G. Alagarswamy, Ph.D., plant physiologist
R.K. Maiti, Ph.D., D.Sc., plant physiologist
K.V. Seshu Reddy, Ph.D., entomologist
V.S. Bhatnagar, Ph.D., entomologist
K.N. Rao, Ph.D., plant pathologist
S.D. Singh, Ph.D., plant pathologist
R.P. Thakur, Ph.D., plant pathologist
R.V. Subba Rao, Ph.D., microbiologist

Pulses

J.M. Green, Ph.D., principal plant breeder (pigeonpea) and leader
A.K. Auckland, Ph.D., principal plant breeder (chickpea)
L.J.G. van der Maesen, Ph.D., principal botanist
W. Reed, Ph.D., principal entomologist (as of Feb 1977)
Y.L. Nene, Ph.D., principal pathologist
A.R. Sheldrake, Ph.D., principal physiologist
P.J. Dart, Ph.D., principal microbiologist
D. Sharma, Ph.D., senior plant breeder (pigeonpea)
K.B. Singh, Ph.D., senior plant breeder (chickpea)
K.B. Saxena, Ph.D., plant breeder (pigeonpea)
L.J. Reddy, Ph.D., plant breeder (pigeonpea)
B.V.S. Reddy, Ph.D., plant breeder (pigeonpea)
K.C. Jain, M.Sc., plant breeder (chickpea)
Onkar Singh, M.Sc. (Ag.) plant breeder (chickpea)
S.C. Sethi, Ph.D., plant breeder (chickpea)
C.L.L. Gowda, Ph.D., plant breeder (chickpea)
R.P.S. Pundir, M.Sc. (Ag.), botanist (genetic resources)
A.N. Murthi, Ph.D., botanist (genetic resources)
A. Narayanan, Ph.D., plant physiologist (until Nov 1976)
N.P. Saxena, Ph.D., plant physiologist
I.V. Subbarao, Ph.D., plant physiologist (as of Mar 1977)
S.S. Lateef, Ph.D., entomologist
M.P. Haware, Ph.D., plant pathologist
M.V. Reddy, Ph.D., plant pathologist
J. Kannaiyan, Ph.D., plant pathologist
O.P. Rupela, Ph.D., microbiologist
J.V.D.K. Kumar Rao, Ph.D., microbiologist

Groundnuts

R.W. Gibbons, B.Sc. (Hons.), D.A.S., D.T.A., principal plant breeder
W.C. Gregory, Ph.D., consultant
D.V.R. Reddy, Ph.D., senior plant pathologist
A.M. Ghanekar, Ph.D., plant pathologist (as of Nov 1976)
P. Subramanyam, Ph.D., plant pathologist (as of Nov 1976)
S.N. Nigam, Ph.D., plant breeder
V.R. Rao, Ph.D., botanist (genetic resources)
P.T.C. Nambiar, Ph.D., microbiologist

Farming Systems

B.A. Krantz, Ph.D., principal agronomist and leader
J. Kampen, Ph.D., principal agricultural engineer (soil and water management)
M.B. Russell, Ph.D., consultant (soil physics)
S.M. Virmani, Ph.D., principal agroclimatologist (as of Jan 1977)
R.W. Willey, Ph.D., principal agronomist (as of Aug 1976)
L.P.A. Oyen, M.Sc., assistant agronomist (as of Oct 1976)
G.E. Thierstein, M.S., principal agricultural engineer, small implements development (as of Nov 1976)
M.C. Klaij, M.Sc., assistant agricultural engineer, small implements development (as of Jan 1977)
F.P. Huibers, M.Sc., assistant agricultural engineer, soil and water management (as of Mar 1977)
S.V.R. Shetty, Ph.D., agronomist
M.R. Rao, Ph.D., agronomist
Piara Singh, M.Sc, soil scientist
Sardar Singh, Ph.D., soil scientist
T.J. Rego, Ph.D., soil scientist
S.J. Reddy, Ph.D., agroclimatologist
M.V.K. Siva Kumar, Ph.D., agroclimatologist (as of Mar 1977)
J. Harikrishna, M.Sc., agricultural engineer
R.C. Sachan, M.Tech. (Agr. Eng'g), agricultural engineer
Harbans Lal, M.Tech., agricultural engineer

P. Pathak, M.Tech. (Agr. Eng'g), agricultural engineer
P.N. Sharma, M.Tech., agricultural engineer
S.K. Sharma, B.A., senior research technician
S.N. Kapoor, M.Sc., (Ag.), senior research technician

Economics Program

J.G. Ryan, Ph.D., principal economist
M. von Oppen, Ph.D., principal economist
H.P. Binswanger, Ph.D., principal economist (ADC)
V.S. Doherty, Ph.D., principal social anthropologist
N.S. Jodha, Ph.D., senior economist
V.T. Raju, Ph.D., economist
S.L. Bapna, Ph.D., economist
B.C. Barah, Ph.D., economist

Biochemistry and Common Lab Services

R. Jambunathan, Ph.D., principal biochemist
Umaid Singh, Ph.D., biochemist

Farm Services

E.W. Nunn, B.S. (Agr. Eng'g), principal agricultural engineer
D.S. Bisht, B.Sc. (Ag. & AH) (Hons.), senior engineer
B.K. Sharma, B.Sc. (Ag. Eng'g.), senior engineer
D.N. Sharma, B.Sc. (Ag.) Eng'g & Tech., senior engineer
S.K.V.K. Chari, M.Sc, electronics engineer
V. Lakshmanan, executive assistant
P.M. Menon, B.A., L.LB., executive assistant

Library and Documentation Services

T.C. Jain, M.Lib.Sci., librarian

Information Services

J.W. Spaven, B.S., head, information services (as of Aug 1976)
G.D. Bengtson, B.S., research editor (as of Oct 1976)
S.M. Sinha, N.Dip. Com.Art, senior artist and printshop supervisor
H.S. Duggal, head photographer
Mira Shah, M.A. (French), French translator/interpreter (as of Nov 1976)

Computer Services and Statistics

J.W. Estes, M.S., computer services officer
J.A. Warren, Ph.D., consultant
T.B.R.N. Gupta, B.Sc. (Jr. Cert. Agrl. Stat.), computer programmer
B.K. Chakraborty, M. Statistics, computer programmer

Plant Quarantine

K.K. Nirula, Ph.D., plant quarantine officer

Fellowships and Training

D.L. Oswalt, Ph.D., principal training officer
A.S. Murthy, Ph.D., senior training officer

Physical Plant Services

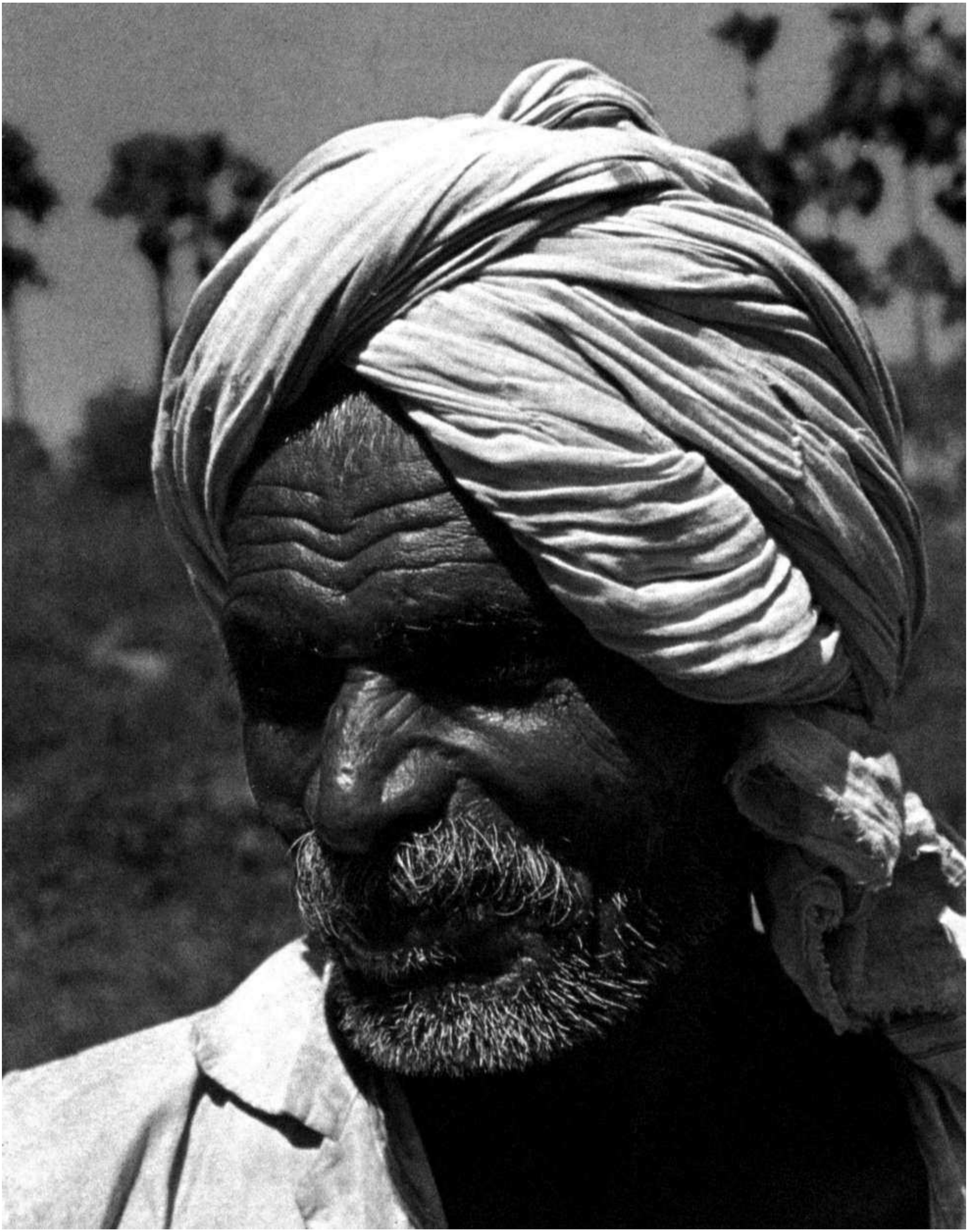
A.D. Leach, Ph.D., engineer (until Dec 1976)
N.N. Shah, Ph.D., project manager (as of Jul 1976)
F.J. Bonhage, construction supervisor
Sudhir Rakhra, B.E., senior engineer
B.H. Alurkar, B.E. (Civil), M.I.C.E. (Ind.), senior engineer
D. Subramanyam, B.E. (Elec), senior engineer
S.K. Tuli, Dip. (Civil Eng'g.), senior engineer (as of Sep 1976)
T.J. Choksi, B.E., L.LB., senior engineer (as of Jan 1977)

Acronyms and selected abbreviations used in this Annual Report:

AICMIP	All-India Coordinated Millets Improvement Project
AICORPO	All-India Coordinated Research Project on Oilseeds
APAU	Andhra Pradesh Agricultural University
BARC	Bhabha Atomic Research Centre
CIBC	Commonwealth Institute of Biological Control
CIMMYT	International Maize and Wheat Improvement Center
CNRA	Centre National de Recherches Agronomiques
COPR	Centre for Overseas Pest Research
CPPTI	Central Plant Protection Training Institute
DPAP	Drought-Prone Area Programme
EAAFRO	East African Agriculture and Forestry Research Organization
FAO	Food and Agricultural Organization of the United Nations
IBPGR	International Board for Plant Genetic Resources
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Centre for Africa
IPMAT	International Pearl Millet Adaptation Trials
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMDRTP	International Pearl Millet Disease Resistance Testing Program
IRAT	Institute for Tropical Crops Research
ISDMN	International Sorghum Downy Mildew Nursery
ISDRTP	International Sorghum Disease Resistance Testing Program
ISGMN	International Sorghum Grain Mold Nursery
ISLDN	International Sorghum Leaf Diseases Nursery
SMIC	Sorghums and Millets Information Center
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development

Abbreviations:

BNV	bud necrosis virus
CRISP	Crop Research Integrated Statistical Package
CSV	chlorotic spot virus
DBC	dye-binding capacity
ET	evapotranspiration
DEP	dilution end point
DM	downy mildew
FSPS	full-sib progeny selection
FYM	farm-yard manure
GMS	gridded mass selection
HYV	high-yielding variety
HI	harvest index
IP	Indian pennisetum
LDC	less-developed country
LER	land-equivalent ratio
MAI	moisture availability index
MKJ	micro-Kjeldahl
PE	potential evaporation
PMHT	pearl millet hybrid trials
PPMRN	preliminary pearl millet rust nursery
PMV	peanut mottle virus
PSV	peanut stunt virus
RRPS	recurrent restricted phenotypic selection
RUE	rainfall-use efficiency
SAT	semi-arid tropics
SCU	sulphur-coated urea
TAA	Technicon auto analyzer
TIP	thermal inactivation point
TSWV	tomato spotted wilt virus
UDY	UDY-instrument reading representing percent transmission
VB	vein-banding disease
WMI	weighted mean index

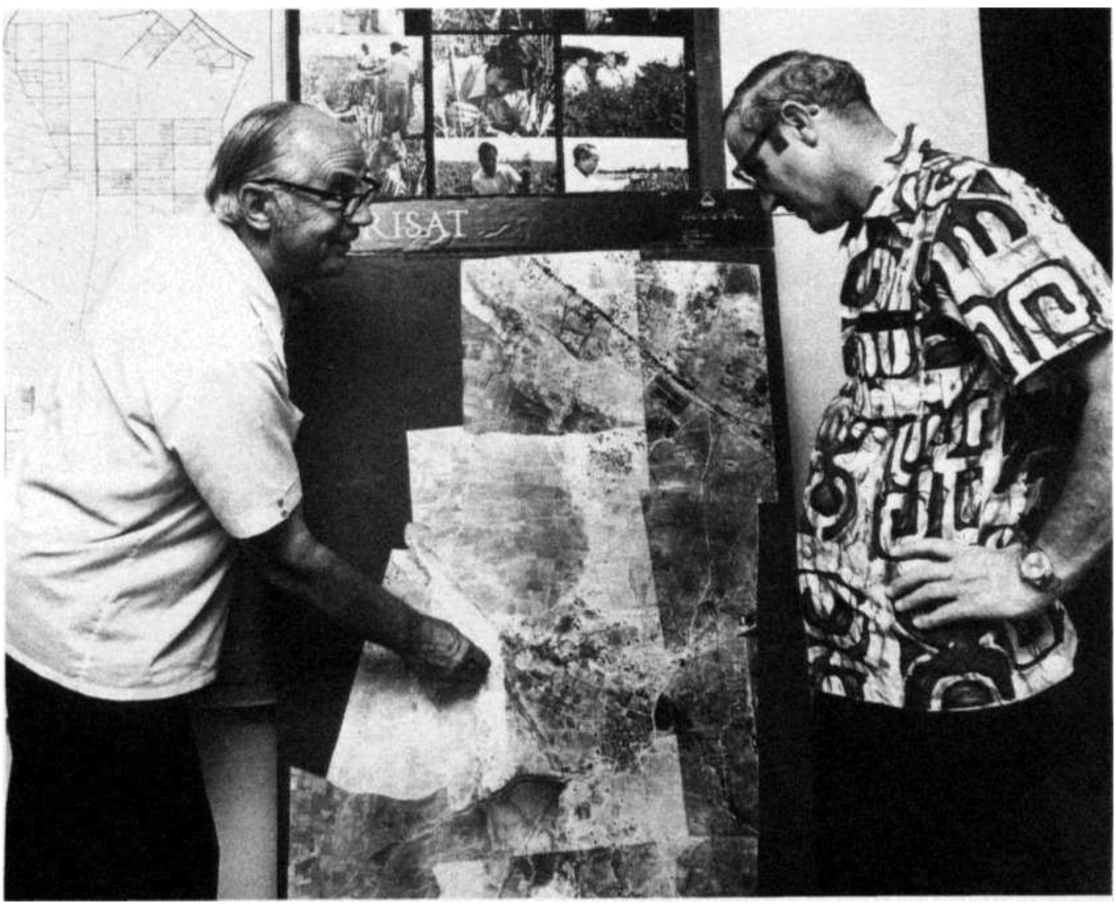


ICRISA T is dedicated to helping the small SA T farmer of limited means . . .

Director's Introduction

The year described in this annual report finds ICRISAT in the busiest stages of its initial development. The earliest programs in Farming Systems, Cereals, and Pulses have established their major organizational lines, appointed most of their senior staff, and formulated and implemented sound research programs. Even some early results are evident in farming systems technology and new millet cultivars. Village level studies in the Economics Program have progressed far enough to give some clear indications of the types of new technology that will be usable by the

Orientation. Retiring Director Cummings (left) explains rationale of field layout at ICRISAT Center to incoming Director Swindale.



Overall direction of ICRISAT is vested in its Governing Board, consisting of 13 members representing 12 nations. The Board, under the chairmanship of Dr. C. F. Bentley of the University of Alberta in Canada, met in Hyderabad in May.

small farmer in the semi-arid tropics. The newest program, in groundnuts, has completed its first full year of operations, although only one quarter of its principal staff has been appointed.

The development of the ICRISAT research farm has kept pace with the growing volume of research. Additional precision fields for crop breeding research and additional watersheds for operational research in farming systems have been developed. Because Hyderabad is not adequately representative of all the semi-arid tropics, small substations in different agroclimatological zones in India are being developed with the cooperation of the state agricultural universities. The substations extend the range of climates and seasons for which cultivars can be developed, and increase the numbers of diseases and pests against which we can develop resistance.

A high point of the ICRISAT year was the November visit of Robert F. McNamara, President of the World Bank. Mr. McNamara and his party toured the major research plots at ICRISA T Center, and then participated in a seminar presented by program leaders.

The construction of ICRISAT Center got off to a slow start in 1975 because of the prolonged monsoon period which greatly interfered with excavations. It has taken a while to overcome the problems created by that very wet season, but construction is now well in hand, although the buildings are not likely to be completed for another 12 months or more.

At its 1977 meeting, the Governing Board of ICRISAT made an important addition to the mandate. ICRISAT agreed to become a primary repository of the five crops included in its mandate and of three minor millets - Proso millet (*Panicum miliaceum*), finger millet (*Eleusine coracana*), and foxtail millet (*Setaria italica*). ICRISAT expects in the future to make major contributions to the collection, description, preservation, and distribution of these genetic resources. The intention is to complement the work of national genetic resources programs and to provide a service to them and to plant breeders throughout the world. This new initiative will require new programs, staff, and facilities in the future.

After several years of testing, we are growing confident that farming systems technologies developed at ICRISAT may enable much more effective use of the deep Vertisols of India during the rainy season.

As ICRISA T's crop-improvement programs grow, thousands of seed samples are shipped to and received from all areas of the world. To prevent accidental introduction of dangerous plant pathogens or other pests and to reduce the amount of time required for quarantine clearance, close cooperation between ICRISAT scientists and quarantine officials of the Government of India is essential. Both parties are working very hard to achieve a rapid and safe flow of material through import and export channels.

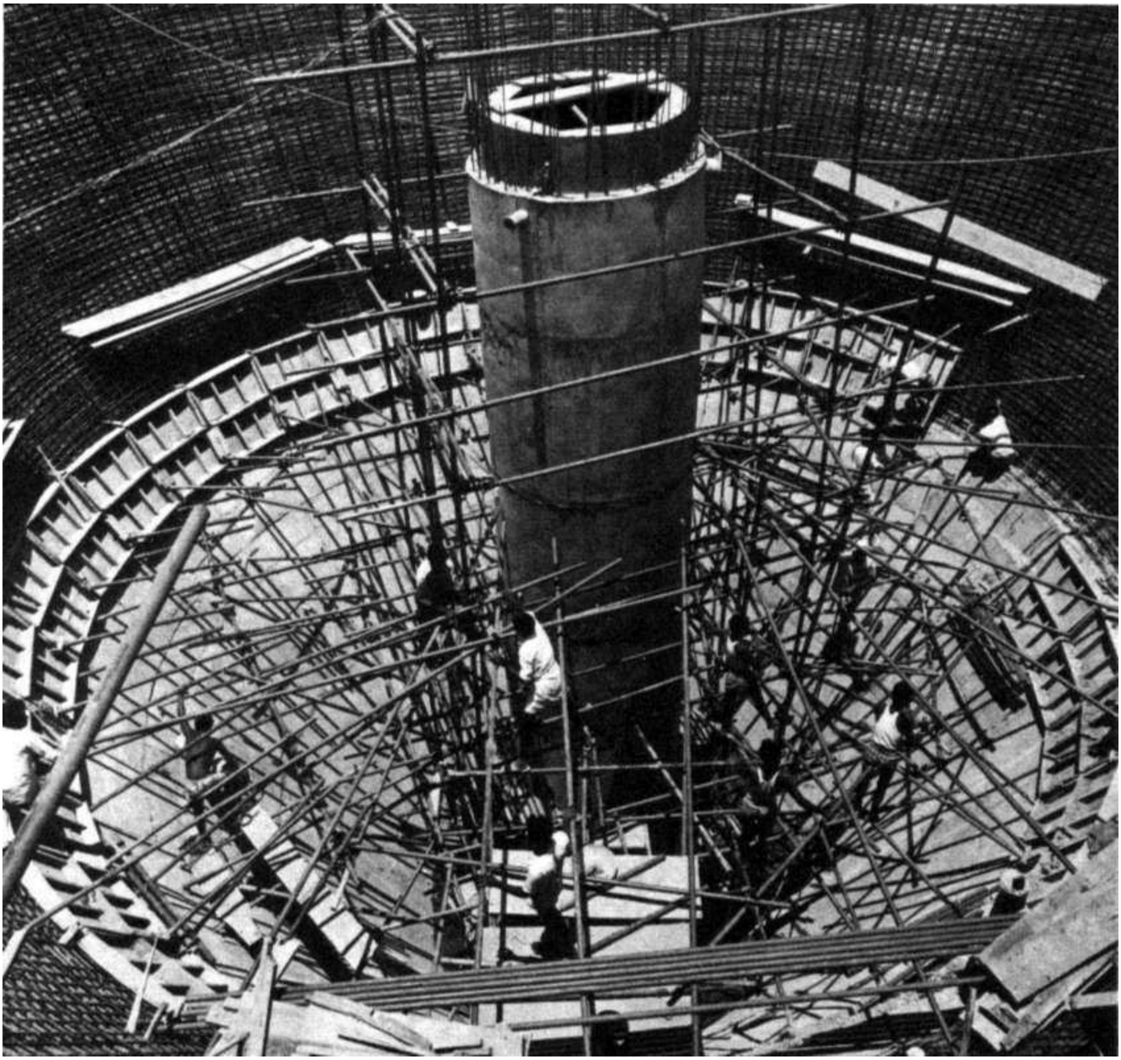
Research has reached the stage where it can now be tested on farmers' fields in the villages of rural India.

ICRISAT workers in pearl millet have successfully developed some new cultivars which have been included in the All-India Coordinated Millet Improvement Project trials. In addition to greater yields, the cultivars have improved resistance to downy mildew, the most prevalent and devastating disease of the crop. Pearl millet will probably be the first improved crop developed at ICRISAT to be incorporated into commercial use in India.

The International Sorghum Workshop brought together 52 sorghum specialists from 26 nations who spent a week discussing sorghum-improvement programs, visiting ICRISAT plots, selecting seed material for their own programs, and exchanging ideas. The country papers presented by the participants provided an up-to-date assessment of the sorghum situation in SAT countries, and is used in the planning of international experiments and programs.

Adama Moussa (left), S.M.Bonzi (center), and A.B.M.Salahuddin (right), former ICRISAT trainees, returned to Hyderabad to participate in the Sorghum Workshop in March. Moussa is doing sorghum breeding work in Niger; Bonzi is serving as entomologist in Upper Volta, and Salahuddin is doing breeding work in Bangladesh. They enjoyed a reunion with Dr. R. C. McGinnis, Associate Director for International Programs (second from left), and Training Officer Dr. Dallas Oswalt.

This year saw the Training Program of ICRISAT reach its peak in numbers. Twenty-seven in-service trainees, most of them from Africa and about half of them from French-speaking Africa, are currently undergoing intensive field-oriented studies in crop production, crop improvement, and farming systems. Eleven research scholars studying for advanced degrees, six research fellows, and three Dutch Associate Experts are also learning-by-doing at ICRISAT. The capacity of our training facilities has been reached, perhaps over-reached, and no larger numbers of trainees can be accommodated until ICRISAT Center has been completed. More than one-hundred trainees in total have already passed through ICRISAT's programs and are now contributing to their national programs, and in some cases to ICRISAT's programs, in their own countries. We wish them well in their future careers and professions.



Work continued on the ICRISAT water tower, which will become the Center's most distinguishing landmark.

In 1974 and 1975 ICRISAT, with the financial assistance of UNDP and the USAID, placed 14 scientists in the Sahelian Zone of West Africa to work at national research stations on sorghum and millet improvement. This year we were able to complement that team by additional researchers in two Sahelian countries and in the Sudan. Our scientists add strength to on-going work in the countries where indigenous scientists are few in relation to the needs.

As the result of the work done during its first 5 years, ICRISAT has reached the stage, where it will be increasingly in a position to offer results which can be applied in farmers' fields. However, the data from which extension recommendations are made to farmers must be carefully analyzed with reference to socio-economic and sociocultural factors which influence the feasibility of adoption of the recommended practices in different areas. Recognizing this situation, the Govern-

Construction began on the ICRISAT auditorium in the general administrative complex. Occupation of the new quarters is expected to be possible near the end of 1978.

ing Board has established a standing Extension Advisory Committee which will judge the value of new technology and information produced by ICRISAT research and indicate to our government and farmer clientele what new things are considered ready for use.

After 5 years of service, four members of the Governing Board are retiring from its membership this year. Mr. Francis Bour, Director General of IRAT, France, and Mr. Rubens Vaz da Costa, businessman of Brazil, have completed their terms. They have assisted ICRISAT in formulating and implementing its initial policies and programs, and made a special contribution to the development of programs in French-speaking Africa and in Latin America. Mr. B. D. Pande, Cabinet Secretary to the Government of India, and Dr. N. Bhagwandas, Chief Secretary of Andhra Pradesh, are retiring from these positions and consequently from the ICRISAT Board. These gentlemen have made exceptionally important contributions to the establishment of ICRISAT in India and developed a commitment by government that will stand to our advantage for manyyears to come. We wish them well in their retirement.

Dr. Ralph W. Cummings, after 20 years in international agriculture and 5 years as the first Director of ICRISAT, has retired from ICRISAT and its Governing Board. Words cannot adequately describe all that he has done for us. To put it simply, he was just the best man that could have been found to put ICRISAT on the right road. His combined knowledge of international agricultural research and of India were unique. Dr. Cummings has assumed the chairmanship of the Technical Advisory Committee to the Consultative Group on International Agricultural Research. From this vantage point he will continue to assist and advise upon the future development of ICRISAT. His vast contributions are gratefully acknowledged.

ICRISAT again acknowledges the cooperation and assistance received from the Governments of India and Andhra Pradesh throughout the year. Wc acknowledge also the growing and fruitful cooperation with scientific institutions around the world.

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	Sorgho	Petit mil, millet, mil à chandelles	Pois d'Angole	Pois chiche	Arachide
Portuguese	Sorgo	Painço pérola	Guando, feijão-guando	Grão-de-bico	Amendoim
Spanish	Sorgo, zàhina	Mijo perla, mijo	Guandul	Garbanzo, garavance	Mani
Hindi	Jowar, jaur	Bajra	Arhar, Tur	Chana	Mungphali

Research Highlights

Sorghum

A major highlight in the sorghum-improvement program during the year was the success obtained in screening for *Striga* resistance in the laboratory and subsequent confirmation of resistance in many lines in field screening. The collaborative work between the breeders and physiologists on mechanisms of mechanical resistance is providing extremely useful data.

Preliminary results from the population-breeding program have identified several lines with yields in excess of those obtained with released cultivars; results of this nature in such a short time is very encouraging.

The identification of a range of germplasm with resistance to several diseases and pests augurs well for production of lines from the breeders' programs incorporating better yield stability. Some of these lines appear to have resistance to *Striga.*

The very useful links forged with cooperators overseas and the extremely encouraging start

Many agricultural officials of cooperating nations visited ICRISAT breeding plots during the year.

made by the ICRISAT programs in Africa are already paying dividends in production of base data, identification of stable lines, and exchange of germplasm.

The collection of sorghum germplasm is increasing and a useful catalog is being built up. Considerable progress has been made on computerization of data.

Pearl Millet

An effective technique was developed for creating uniformly high disease pressure for downy mildew in both the rainy and postrainy seasons. Breeders now screen up to 6000 entries for downy mildew resistance per season on 5 hectares, and conduct breeding operations in this disease nursery.

Valuable results were obtained from 1976 International Cooperative Nurseries. The International Pearl Millet Downy Mildew Nursery (IPMDMN) identified 10 lines (mostly of Nigerian origin) with across-location DM resistance. The best entry in the Second International Pearl Millet Adaptation Trial (IPMAT-2), an ICRISAT hybrid (ICH 105-5054 x B 282), averaged 27 percent more yield than the local varieties (1934 kg/ha) over 30 locations. The best variety WC-C75, also from ICRISAT, gave 10 percent more than the local variety average.

The All-India Coordinated Millet Improvement Project (AICMIP) selected, from the results of country-wide trials, ICH 105 and WC-C75 for advanced testing. Variety WC-C75 is a first-cycle product of the ICRISAT population-improvement program. The parents of hybrid ICH 105 were released to the National Seeds Corporation for increase.

Tests for progress in the population-improvement program indicated a slight but nonsignificant yield gain of about 5 percent due to the first cycle of multilocation selection in seven composites with no indication of reduced genetic variability. Experimental varieties produced from these populations have equalled the yields of commercial hybrids, and the best progenies have given up to 25 percent more yield than the parent population.

Seed requests from cooperators increased. During the year a total of 5 153 germplasm and breeding lines (excluding cooperative trials) were supplied to scientists. in 18 countries.

Pigeonpea

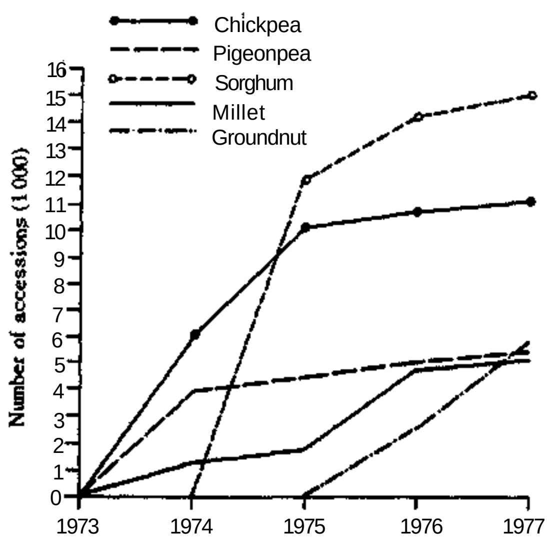
Collection of *Atylosia cajanifolia,* apparently the closest wild relative of pigeonpea, provided additional genetic resources for breeding.

Differential response of cultivars in pure crop and in cereal/pigeonpea intercrops emphasized the importance of selecting under actual production conditions; we have planted breeding materia] in intercrops with maize and with sorghum.

A laboratory-screening technique for *Phytophthora* stem blight was developed, and resistant cultivars have been identified.

A field-screening method for sterility mosaic disease utilizing infector rows was developed.

Antibiosis in *Atylosia scarabaeoides* to *Heliothis armigera* was found. This, plus anatomical differences in pods of the two genera, are the first



Germplasm accessions at ICRISAT.

indications of possible specific characters that might confer resistance to *Heliothis.*

Postrainy season planting of medium-duration cultivars at high population levels gave grain yields of 1 500 to 1 700 kg/ha.

Chickpea

Among the first advanced breeding lines furnished to cooperators, one early and five late lines yielded significantly more than the average of the checks over all locations, and several outstanding lines were selected for increase and further testing by local breeders.

Differences among cultivars in germinability under low levels of soil moisture were found in preliminary experiments. This indicates an important area of research aimed at improved stands of a crop planted on receding moisture.

Among 450 lines grown in a multiple-disease sick plot, 60 with good levels of resistance to soil-borne disease were identified.

Resistance to *Ascochyta* blight was found in two wild species of *Cicer, C. reticulatum,* and C. *anatolicum.* The former has been successfully crossed with the cultivated chickpea.

Seed-borne *Fusarium oxysporum* was eliminated by treatment with 0.15 % Benlate-T, providing a safe means for controlling this fungus in seed exchanged among scientists.

One of the many sorghum breeding nurseries at ICR1SA T.

The efficiency of small plots in screening trials for insect damage was established. This will permit screening many more genotypes in a given area.

Groundnut

In groundnut improvement, we have achieved a very rapid buildup of germplasm to about 6000 cultivars in spite of strict quarantine considerations.

Cultivars with resistance to rust and to yellow mold and interspecific hybrids with resistance to leafspots have gone through quarantine restrictions and are now being used in the breeding program.

Rapid advances have been made in the identification and purification of groundnut viruses, using advanced laboratory techniques. Simple and reliable germplasm screening methods have been evolved for the major viruses being studied.

A rapid and efficient screening technique, using detached leaves for the identification of rust resistance on a large scale under controlled conditions, is being perfected.

Differences in nodulating capacity were noted between germplasm lines. A diurnal periodicity in nitrogenase activity suggests a close link with this activity and photosynthesis.

Farming Systems

Deep Vertisols are normally fallowed during the rainy season in the semi-arid tropics (SAT). Present annual yields of cereal food grains on these soils range from 200 to 600 kg/ha. ICRISAT scientists have developed soil-, water-, and crop-management systems which permit cropping of deep Vertisols during the rainy as well as the postrainy season. These improved farming systems have been tested on operational-scale watersheds for 5 years, using animal draft power and improved equipment. Annual food production has been consistently

A valuable facet of the International Sorghum Workshop was the opportunity for participants to inspect the material growing at ICRISA T Center and select lines that may be useful in their own programs at home. Seed of the selected plants was despatched to the participants after harvest and quarantine clearance.

increased to levels severalfold those of present yields with traditional management. Cooperative research on improved resource management and utilization has been initiated with national programs of the Government of India.

By timely tillage, deep Vertisols can be prepared with improved bullock-drawn implements during the dry season, permitting "dry planting" of crops such as sorghum, pigeonpea and maize just prior to monsoon rains. Because of the low water-retention capacity of Alfisols, dry planting is hazardous and not practiced. By "dry planting" on Vertisols, the first rainfall - which moistens the soil to seed level - is utilized for crop growth and no water is wasted in the land preparation process. "Dry planting" facilitates early growth to provide a plant canopy for light and raindrop interception and facilitates plant establishment ahead of the insect buildup which starts at the onset of the rainy season.

Contour bunding is the most common technique used to conserve soil and water on rainfed lands. Relatively little research has been conducted in India on the effect of contour bunding upon crop yields. Two recent reports on deep Vertisols actually indicate reduced crop yields due to stagnant water and reduced fertility above the contour bunds. Likewise, results from ICRISAT's watershed-based investigations show no positive yield effects from contour bunds even in relatively low rainfall years, as in 1976 and 1977. There were, however, negative effects in many cases due to water stagnation above the bund, particularly in high rainfall years such as 1975. Thus, it appears that no positive moisture-conservation effect upon crop yields can be expected from contour bunding under most conditions in the SAT.

The watershed-based resource utilization system using a graded (150 cm) bed-and-furrow system at 0.4 to 0.6 percent slopes with grassed waterways and runoff collection in small tanks

December planting ofpigeonpea results in greatly reduced growth as a result of short-day induction of early flowering. Entire plants are covered with muslin bags or nylon stockings to prevent cross pollination by wild bees.

shows great potential for reduced soil erosion, more uniform distribution of rain water, improved crop drainage, possibilities for supplemental irrigation particularly on Alfisols, reduced risk, and greatly increased crop yields.

On deep Vertisols the yield of postrainy season crops was little affected by growing rainy season maize instead of the traditional practice of fallowing. Cropping in both seasons gave substantially better returns than a single postrainy season crop. Sorghum and pigeonpea sown as second crops responded to early sowing; therefore these crops benefitted from "relay" planting 24 days before maize harvest. Chickpea and safflower responded to late sowing, so these performed better as sequential crops after maize.

An experiment conducted on an Alfisol with sorghum compared "traditional" with "improved" levels of three "steps" in technology - variety, fertilization, and soil and crop management—singly and combined. Yield increases from the three steps combined was double that of the sum of the increases due to the same three factors applied singly, thus illustrating the large synergistic effect of the three steps when applied together in a system. Similar results were obtained with sorghum in 1975 and with maize/pigeonpea intercrop on a Vertisol in 1976.

ICRISAT scientists believe that the principles involved in improved farming systems, along with the introduction of high-yielding varieties, will have a great impact on the quantity and stability of food production in the SAT of the developing world.

Economics Program

Village Level Studies have revealed that in regions with less assured rainfall and a more heterogeneous resource base, the proportion of intercrops grown is higher than in the more assured and homogeneous areas. Small farmers in such areas grow a higher proportion of mixed crops than do large fanners. Successful intercropping research may therefore benefit less well-endowed regions and farms. The fact that virtually all high-yielding varieties were found to be grown as sole crops suggests, though, that the importance of intercrops declines when HYVs are introduced. Improvements in land and water management which enhance the resource base and make it more homogeneous may encourage more sole cropping.

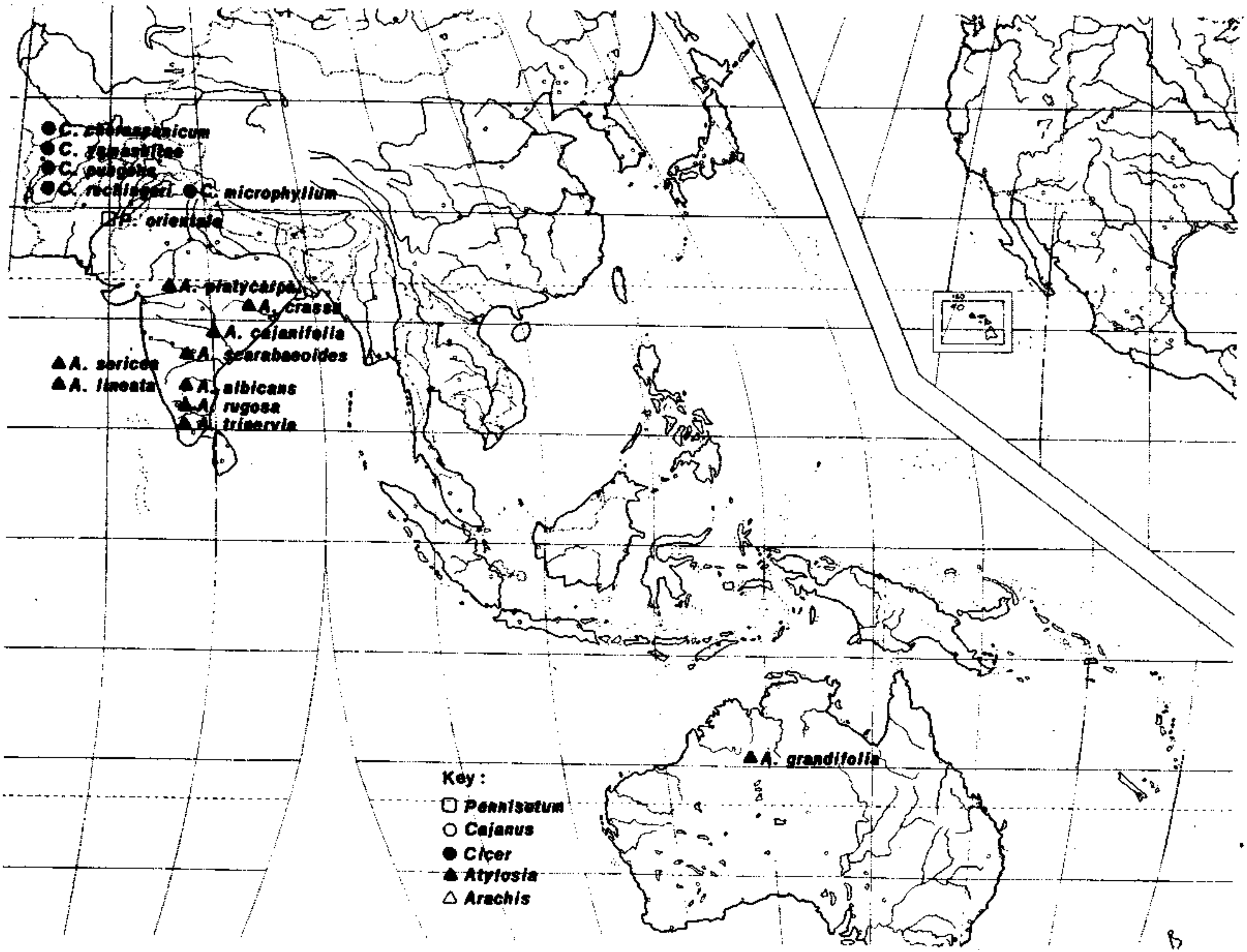
Small farmers in the deep Vertisol village studied were found (when compared with large farmers) to leave a higher proportion of their land fallow during the rainy season. To the extent that this is true generally in the 18 million hectares of such fallow land in SAT India, technology which enables more cropping in the rainy (as well as the postrainy) season may have substantial benefits for small farmers.

Farmers in the village level studies practiced weed control more intensely and timely on the higher-valued crops and where weeds were more vigorously growing, such as in rainy season crops. With HYVs, farmers would be expected to improve their weed-control efforts. Herbicide research in SAT India does not seem to be a high-payoff proposition; with abundant labor and animal power and low wage rates weed control with herbicides is at least SO percent more expensive than with animal and human methods. Herbicides can also have adverse effects on income-earning opportunities for one of the most disadvantaged groups in SAT India - female labor (particularly hired female labor). Hence, both on grounds of productivity and equity, herbicide research seems a low priority for SAT India unless it can provide substantial yield gains not possible with human and animal methods. The situation in SAT Africa may be quite different.

During drought periods farmers were found to reduce consumption and the value of productive farm assets. Formal credit agencies provided only 13 percent of sustenance needs; the bulk of borrowing was from private lending sources. Government relief works were the major source of sustenance in droughts. It was concluded that more-flexible credit policies in high-risk SAT areas would be of great value in terms of adjusting to meet the requirements of fanners during droughts-particularly in maintaining the value of productive assets. Credit linked with the development and introduction of risk-diffusing technology would be beneficial.

The net nutritional impact of the new HYVs of wheat introduced in India in the mid-1960's was positive and substantial. This success clearly illustrates how a plant-breeding strategy which emphasizes increased yield potential can lead to significant improvements in aggregate nutritional well-being.

Figure 1. Wild relatives of pearl millet, pigeonpea, chickpea, and groundnut in the ICRISAT germplasm collection, by area of origin.



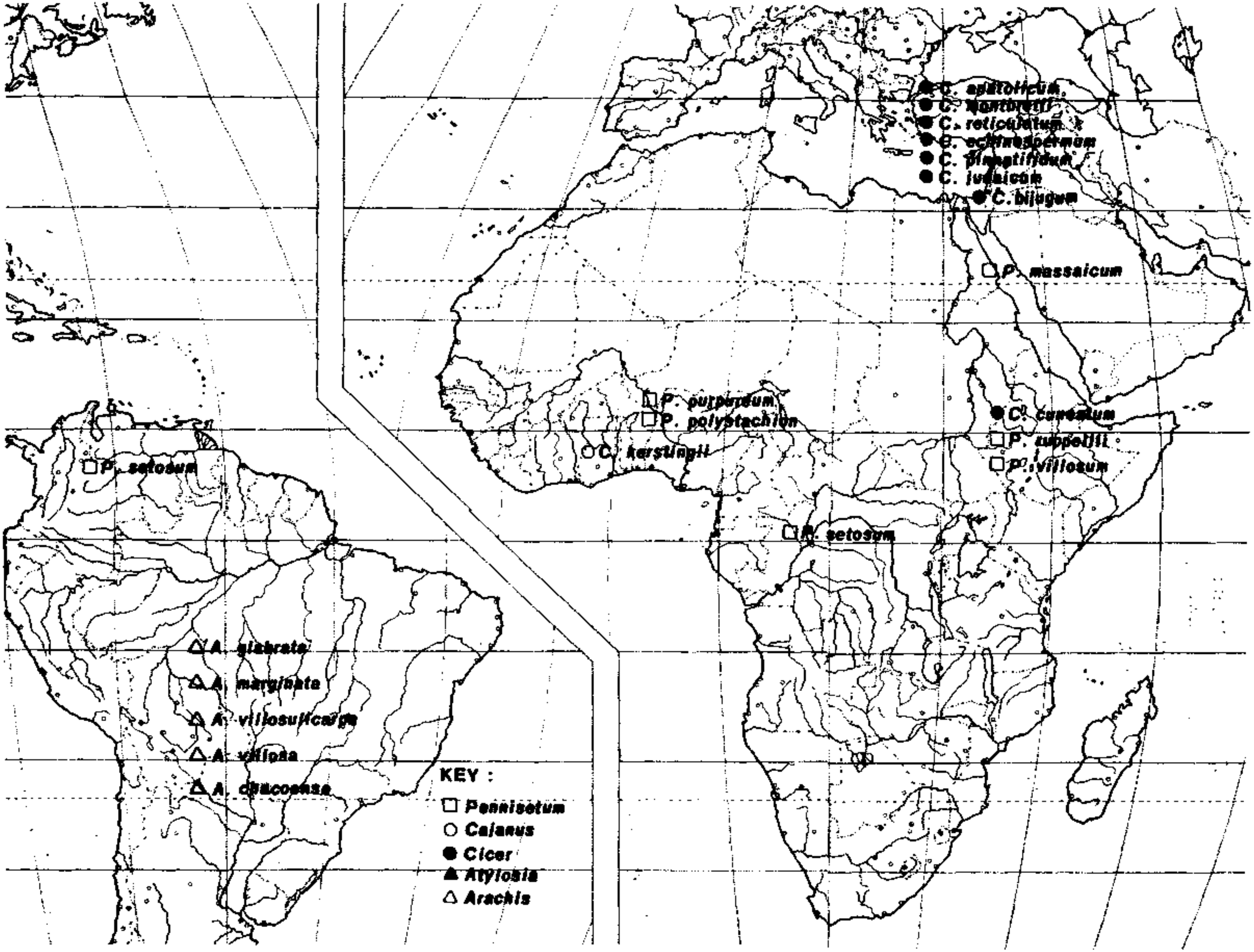
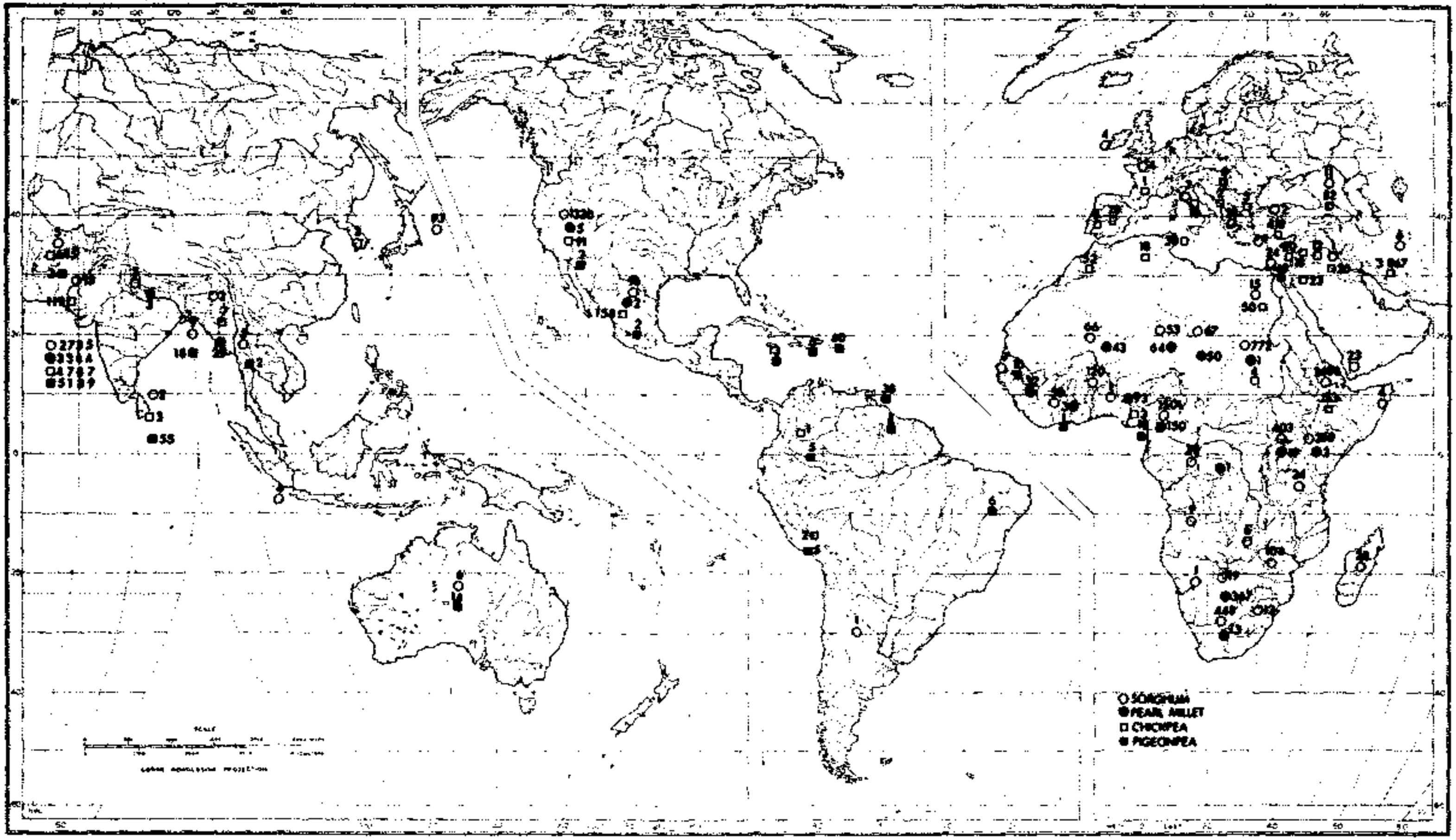

C. anatolicum
C. montbretii
C. reticulatum
C. echinospermum
C. pinnatifidum
C. judaicum
C. bijugum
P. massaicum
P. purpureum
P. polystachion
C. kerstingii
C. cuneatum
P. ruppelii
P. villosum
P. setosum
P. setosum
A. glabrata
A. marginata
A. villosulicarpa
A. villosa
A. chacoense
KEY :
Pennisetum
Cajanus
Cicer
Atylosia
Arachis

Figure 2. Origin of germplasm accessions in the ICRISAT collection, as of June 1977. The origin of a large number of accessions obtained by ICRISAT is uncertain; that of more than 5 000 groundnut accessions is still to be ascertained.



THE CEREALS

Sorghum (*Sorghum bicolor*)

Pearl Millet (*Pennisetum americanum* L.)

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

The quantum leaps seen in production of rice and wheat, brought about by high-yielding varieties and research-based technology, have in no way been matched by sorghum and pearl millet. Farm practices remain essentially as they have been for thousands of years. A worldwide effort in breeding superior varieties is just now getting under way, and much remains 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.

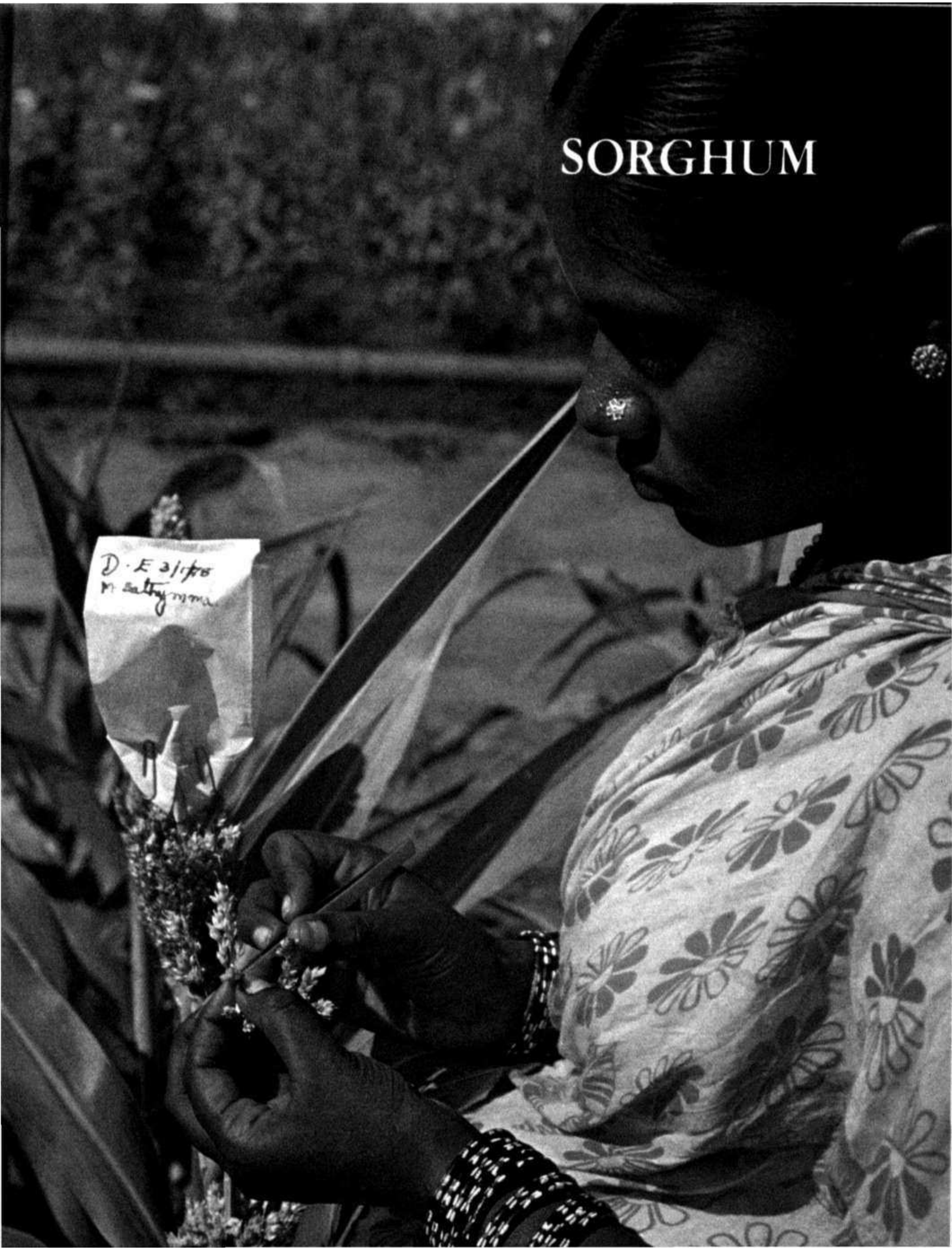
Improved nutritional value, cooking quality, and palatability.

ICRISAT scientists are pursuing these goals at ICRISAT Center near Patancheru Village 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 Alfisols and Vertisols 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 postrainy season, known locally as postmonsoon or rabi and occupying the months of October through January, has little rainfall and is cooler and days are shorter. Crops grown during the postrainy 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



Sorghum

Germplasm

Collection and Maintenance

The total number of accessions in our collection increased, with the addition of 797 lines, to 15037. We rejuvenated 7930 accessions by selfing five to ten representative heads. Ninety-seven primitive sorghum types and landrace material were collected in the hilly areas of Andhra Pradesh and Orissa (Eastern Ghats). Additional material was obtained from cooperators in West Africa, Bangladesh, USA, Sudan, Sri Lanka, and the Lebanon. A valuable collection of 414 farmers' types was sent to us from Ethiopia.

Evaluation and Classification

The collection was evaluated for morphological and agronomic characters including plant height, days to 50-percent flowering, awning, mid-rib color, plant pigmentation, tillering, peduncle exsertion, earhead length and breadth, panicle type, glume color, 100-seed weight, threshability, luster, presence of subcoat, and endosperm texture. In addition more than 2 700 lines were assessed for resistance to diseases, insects, and *Striga.* Considerable material was supplied for use in the breeding, biochemistry, physiology, and microbiology programs. We provided nearly 6000 germplasm samples to cooperating agencies in India and abroad (Table 1).

A pilot catalog of 300 accessions grown in postrainy season 1974 was prepared in collaboration with the Information Sciences/ Genetic Resources Program, University of Colorado. We have sent additional information on 7 215 lines to its laboratory for preparation of an expanded catalog. The collection has been completely classified according to Harlan and de Wet's Scheme, and panicle branches have been preserved for future reference.

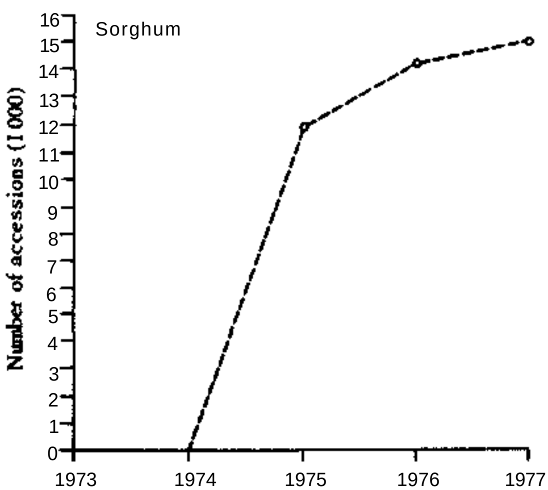


Figure 3. Sorghum germplasm accessions at ICRISAT Center.

Introgression

We initiated research on introgression of genes from the germplasm into adapted breeding material; diploids and tetraploids are included in the study. Desirable segregants with large heads, bold grains, dwarf plants and photoinsensitivity were obtained from F_2 and (BC_1) F_2 populations utilizing CSV_5 as the adapted cultivar and landrace material from Ethiopia, Ghana, and Cameroon. Work continues.

A broader-based project, involving parental material from selected landraces from the kaoliangs, good-grain dochnas, yellow and corneous endosperm kafirs, caudatums, conspicuums, and dura kauras, zera zeras, and good guineas and using the adapted cultivars CSV_5, M35-1, NI_3 Nandyal, 954063 (T x 3927-4), and 954062 (T x 3925-2) is under way. Already we have made 808 fresh crosses.

Breeding

The dominant objective in the breeding program has continued to be increased sustained yields in the highly variable semi-arid environment.

Table 1. Sorghum germplasm lines supplied to research agencies in India and other nations during 1976-1977.

Institution	Location	Entries
INDIA:		
All-India Coordinated Sorghum Improvement Project	Hyderabad, A.P.	39
Andhra Pradesh Agricultural University	Hyderabad, A.P.	114
Millet Research Station	Madhira, A.P.	40
Cotton Research Station	Nandyal, A.P.	13
Millet Research Station	Podalkur, A.P.	11
Andhra University	Visakhapatnam, A.P.	9
Haryana Agricultural University	Hissar, Haryana	840
Kashmir University	Srinagar, J&K	10
College of Agriculture	Dharwar, Karnataka	260
Punjabrao Krishi Vidyapeeth	Akola, Maharashtra	678
Agricultural Research Station	Mohol, Maharashtra	19
Marathwada Agricultural University	Parbhani, Maharashtra	45
Deccan College	Poona, Maharashtra	20
Mahatma Phule Krishi Vidyapeeth	Rahuri, Maharashtra	24
Punjab Agricultural University	Ludhiana, Punjab	20
Rajasthan College of Agriculture	Udaipur, Rajasthan	39
Sugarcane Breeding Institute	Coimbatore, Tamil Nadu	5
Tamil Nadu Agricultural University	Coimbatore, Tamil Nadu	48
Regional Station for Forage Production & Demonstration	Madras, Tamil Nadu	37
Indian Grassland & Fodder Research Institute	Jhansi, U.P.	331
G. B. Pant University of Agriculture & Technology	Pantnagar, U.P.	53
OTHER NATIONS:		
Agricultural Research Institute	Bangladesh	384
Mennonite Central Committee	Maijdi Court, Bangladesh	10
Dr. Mario Lira .	Brazil	9
IDRC	Canada	4
Mr. Guitierrez	Palmira, Colombia	10
Chinese Academy of Agricultural & Forestry Sciences	People's Republic of China	36
Asian Vegetable Research & Development Centre	Republic of China	25
Ministerio de Agricultura y Ganaderia	El Salvador	36
Ethiopian Sorghum Improvement Project	Ethiopia	1387
EAAFRO	Kenya	470
Agricultural Research Centre, UNDP	Libya	20
Shire Valley Agricultural Development Project	Malawi	98
School of Biological Sciences	Malaysia	10
University of Agriculture	Malaysia	62
University of Malaya	Malaysia	25

continued

Table 1 *continued*

Institution	Location	Entries
CIMMYT	Mexico	142
Centre Regional de Formation et d'Application en Agrometeorologie et Hydrologie operationnelle	Niger	28
Chinese Agricultural Technical Mission	Saudi Arabia	27
Hofuf Agricultural Research Centre	Saudi Arabia	14
University of Khartoum	Sudan	25
University College of North Wales	Bangor, United Kingdom	5
Tropical Products Institute	United Kingdom	100
Purdue University	Indiana, USA	12
Texas A&M University	USA	12
N.I. Vavilov Institute of Plant Industry	Moscow, USSR	239
CIARCO-Venezuela	Venezuela	3
United States of America Embassy	Sana'a, Yemen Arab Republic	20
UNDP	Yemen	50
Eglise du Christ au Zaire	Zaire	4

Figure 4. ICRISAT sorghum breeder selects promising plants from composite populations.

Sorghum Population Improvement

Progress in improving populations is very encouraging. After one or two cycles of selection, six of eight populations show an increase of 21 to 36 percent over the base yield (Table 2). There was a reduction in yield of 8 and 11 percent in the other two populations. These results were achieved even though selection was primarily for white pearly grain, elimination of photosensitivity, and stabilization of populations for plant height. Plant heights were reduced, and there was almost no change in maturity.

Select lines from the composites were evaluated under high fertility (130 kg N, 60 kg P_2O_5/ha on Vertisols) and low fertility (20 kg N, 20 kg P_2O_5/ha on Alfisols) in the rainy season. The performance of selected lines is presented in Table 3. Four lines gave yields not significantly different from the hybrid check (CSH-6) in high fertility; and likewise with 15 lines in low fertility. Three lines yielded significantly more than the best varietal check, 370, in high-fertility Vertisols and 18 lines were significantly superior to CS 3541, the best varietal check on low-fertility

Table 2. Comparison of grain yield, plant height, time to 50 percent flowering, threshing percentage, and 100-seed weight in original and improved sorghum populations at ICRISAT Center, rainy season 1976.

Population	Selection cycles	Grain yield		Plant height		Time to 50% flowering		Threshing percentage		100-seed weight	
	(no)	(kg/ha)	(% change)	(cm)	(% change)	(days)	(% change)	(%)	(% change)	(g)	(% change)
Rs/R		3829		262		63		72.0		2.34	
Rs/R[a]	2 S_1 visual	5201	35.8	204	−22	62	−1.6	73.4	1.9	2.31	−1.3
Rs/B		3559		269		68		72.3		2.19	
Rs/B[a]	2 S_1 visual	4573	28.5	197	−27	64	−5.9	76.9	6.3	2.24	2.3
Tropical Conv.		2944		221		66		68.6		2.22	
Tropical Conv.[a]	2 S_1 visual	3559	20.9	162	−27	66	0	71.1	3.6	2.29	3.2
Serere Elite		3608		250		65		73.4		2.51	
Serere Elite[a]	2 S_1 visual	4368	21.1	219	−12	62	−4.6	73.5	0.1	2.26	−10.0
US/R		4060		210		60		75.0		2.77	
US/R[a]	1 S_1 testing	3720	−8.4	184	−12	63	5	71.1	5.2	2.53	−8.7
US/B		3476		203		60		77.6		2.75	
US/B[a]	1 S_1 testing	4236	21.9	167	−17	63	5	74.9	−3.5	2.50	−9.1
Fast Lane 'R'		3960		172		61		74.0		2.39	
Fast Lane 'R'[a]	1 S_1 visual + 1 S_1 testing	3508	−11.4	146	−15	63	3.2	73.1	−1.2	2.25	−5.9
Fast Lane 'B'		3222		170		62		65.4		2.51	
Fast Lane 'B'[a]	1 S_1 visual + 1 S_1 testing	3710	15.1	146	−14	64	3.2	72.8	11.3	2.44	−2.8

[a]Improved counterparts of the populations.

Table 3. Performance of promising entries in population line evaluation trials on Vertisols and Alfisols at ICRISAT Center during 1976.

Entries	Grain yield Vertisol	Alfisol	Mean	Mean height	Mean time to flowering	100-seed weight	Plant aspect[a]
	(kg/ha)			(cm)	(days)	(g)	
Fast Lane 'R' 101	5442	3370	4406	137	58	2.33	2.3
Rs_1 x VGC	5452	3225	4339	206	58	2.36	2.3
'R' Composite-Red	5215	3277	4246	196	59	2.09	3.0
Fast Lane 'R' 101-Red	4938	3173	4056	132	58	2.24	2.3
Fast Lane 'R' 266	5 307	2385	3 846	158	61	2.73	2.2
Fast Lane'B' 117	4662	3287	3975	137	56	2.62	3.3
Fast Lane 'B' 100	3 773	3111	3442	165	57	2.23	3.3
Rs/R 20	3 398	3101	3250	152	56	2.99	2.7
CSH-6	6074	3526	4800	183	58	2.69	1.7
CSV-3	4301	1504	2902	178	60	2.69	2.2
CSV-4	3 348	1867	2607	147	64	2.45	2.2
L.S.D. (0.05)	961	716	679	10	2.9		
C.V.(%)	15.8	17.0	17.6	4.1	3.0		

[a]Plant aspect is a visual score of general plant attractiveness: 1 = good to 5 =poor.

Alfisols. The experimental lines in this trial were developed with evaluation across seasons and under high- and low-fertility conditions. The indications are that this may be a useful breeding procedure for the selection of stable types. Yields of some of these same lines in the postrainy season were: Fast Lane 'R' 274 (4600 kg/ha); Rs x VGC (4 500 kg/ha); Fast Lane 'R' 101 (4100 kg/ha); and Fast Lane 266 (4000 kg/ha). These are good yields and comparable with those of the rainy season.

Lines from two of the advanced populations were tested during the rainy season at two locations each in India and Ethiopia and at single locations in Upper Volta and Senegal. These lines were simultaneously evaluated for their reaction to shoot fly, grain mold, *Striga,* charcoal rot, and downy mildew. About 40 lines were selected to continue the next cycle.

Preliminary trials were conducted in other populations to identify entries for multilocation evaluation in 1977. Some 600 lines derived from existing populations were evaluated during the rainy season on a multilocation basis; parents to form new populations will be selected from these.

The progress of composite formation, development, and multilocation evaluation is apparent. Potentially useful varieties are now forthcoming.

Breeding for Grain-mold Resistance and Improved Grain Quality

Earlier-maturing types with resistance to grain mold and weathering are important with regard to yield stability. The scope of this project has been broadened from a concentration on early types to include a range of maturities (across various ecological zones) which would be earlier than the locals. A large number of cultivars of diverse origin, maturity, grain-mold reaction, and grain quality have been crossed, and progeny are being evaluated jointly with the cereals pathologists. Selections are listed in Table 4.

Seventy-two elite selections from F_4 progenies were distributed to cooperators in 12 countries outside ofIndia for evaluation in the 1977 rainy season.

In the 1976 "off-season" (postrainy season) nursery, 1 350 new single crosses were made and 400 F_1'sg were advanced; of these, 200 have been selected for evaluation as F_2's in 1977.

Grain quality is being improved by crossing good early lines with others having desired traits - e.g., heavy bold seed, yellow endosperm, pearly white lustrous grain. The process of evaluation, stabilization of a trait, and recrossing is continuous.

Table 4. Selections made in various generations for early good-grain, grain mold-resistant sorghum types at ICRISAT Center, 1976.

Generation	Selections
	(no)
Single cross F_4	748
Single cross F_3	1030
Single cross F_2	1474
Double cross F_3	546
Three-way cross F_2	645
Total	4443

Figure 5. Discussing a sorghum breeding problem at ICRISA T Center.

A mold-resistant composite is being developed to increase levels of mold resistance and to improve grain quality in an agronomically good background through recurrent selection procedures. Currently, male sterility is being incorporated into selected entries.

Mold resistance is being incorporated into advanced populations and an attempt is being made to evaluate the effect of extra-long free-threshing papery straw-colored glumes as barriers to grain mold organisms.

A program initiated to develop cultivars suitable for the postrainy season - incorporating lines with 90 to 105 days maturity, excellent grain quality, substantial fodder value, resistance to shoot fly, and tolerance to drought - has reached the F_2 stage. Seed from 500 crosses is available for evaluation in postrainy season 1977. Yields of some of the photoinsensitive lines tested in the rainy and postrainy seasons 1976 are presented in Table 5.

Attempts to recover sorghum in a plump grain with high lysine content are frustrated by instability in the lysine concentration - with a reversion to lower (normal) lysine levels. Work towards a better understanding of the reasons for this is part of a Ph.D. thesis study now under way at ICRISAT Center.

Across the breeding program, selection for locally desirable grain quality-i.e., bold, reasonably hard, pearly white seed - is practiced. A program to attempt to evaluate breeding stocks for food characteristics is being initiated.

Breeding for *Striga* Resistance

Screening sorghum in the laboratory to identify plants with low or no strigol production is now under way. So far, 3053 cultivars have been screened and 115 were found to have low stimulant production. Some of these have at least partial resistance to shoot fly, midge, grain mold, and other yield reducers, thus enhancing their value to the breeding program. Performance of the top 15 cultivars is compared to that of checks in Table 6. Difficulty in uniform field screening led to large coefficients of variation.

Striga asiatica and *S. densiflora* are found in India, while *S. hermonthica* is found primarily in Savannah Africa. Five Nigerian lines with resistance to *S. hermonthica* were also found to be low-stimulant types for *S. asiatica.* Preliminary data were obtained suggesting that many of the lines which are low-stimulant types for *S. asiatica* were positive for 5. *densiflora;* however there did not appear to be much difference in reaction to S. *asiatica* seed collected from several sites in India (Table 7). These data are being checked.

It is now well established that some sorghum cultivars, though strigol positive, have resistance which operates after *Striga* seed has attempted to parasitize them. In cooperation with the ICRISAT cereal physiology group, studies of the mode of attachment - using root sections of susceptible and resistant genotypes - have been made. The mechanism of resistance appears to be associated with thick-walled endodermal cells and the presence of silica crystals in these cells (see Sorghum Physiology, page 35).

Our field-screening studies at Akola and ICRISAT Center showed that 15 of the 275 entries tested had high levels of resistance (Table 6). These will be incorporated into agronomically elite material.

Inheritance studies indicate that low strigol production is controlled by a single recessive gene. Further studies on the nature of inheritance of other resistance mechanisms will be undertaken with material currently being assembled.

Breeding for Pest Resistance

This program was initiated with the objective of strengthening resistance to the three major pest groups present in the SAT—stem borer, shoot fly, and midge. Available resistance is being incorporated into desirable plant types with good yield and quality traits; populations are being bred to combine higher levels of resistance with agronomically good plants. Resistances found in Indian and African sources were intercrossed, using male sterility, for a second time in the rainy season; progeny of these crosses will be further evaluated. Selections following crossing, backcrossing, and double crossing have been

Table 5. Grain-yield dsta on some elite sorghum selections under high-and the rainy season and medium-fertility conditions during the postrainy season at ICRISAT Center, 1976.

Pedigree	Rainy (high fertility)[1]	Rainy (low fertility)[a]	Postrainy (medium fertility)[a]
	(kg/ha)		
(NP x ALAD) Sib 12-1	5214	3 777	2698
(Bulk Y x IS 511-1)-1-1-2	5703	1 851	2727
(WABC x 954062[b]) Sib 23-1	5 104	1 393	707
Good-grain	5 363	1 896	2611
Good-grain Pop. II	4 985	2 578	2698
(Bulk Y x IS 511-1)-1-1-3	4933	2356	2857
(WABC x Entomology)-7-l	4 800	2015	2077
(Bulk Y x 954062)-10-2-l	4 682	1 703	2987
(Bulk Y x 954062)-3-2-l	4 385	1 778	3 722
(Bulk Y x 954062)-10-2-3	4 311	1 659	2727
(Bulk Y x 954062)-10-2-2	4193	1 882	3549
Downes Bulk-1	4037	1 437	2712
(WABC x Entomology)-10-l	4015	2 830	3694
(Bulk Y x GPR 165)-2-4	4007	1 630	3030
(Bulk Y x 954062)	3644	2 444	2712
Dekalb 15-4 (Yellow)	3 141	1911	3275
(Bulk Y x GPR 165)-4-2	3 015	1 570	3766
(Bulk Y x GPR 165)-4-1	2985	1 304	3463
(Bulk Y x GPR 165)-4-3	2044	770	3968
CSH-1	5239	2670	3304
CSH-6	6133	2 304	1789
CSH-7	-	-	3102
CSH-8	-	-	3116
$UChV_2$	4126	2 037	-
CS 3541	3 822	608	-
GPR 148	2148	1007	-

[a]High fertility reflects 130 kg N and 60 kgP per ha; medium fertility, 40 kgN, 20 kgP/ha; low fertility, 20 kgN, 20 kgP/ha.
[b]954062 is the Texas Agricultural Experiment Station No. Tx 3925-2.

made to incorporate greater levels of tolerance into 26 elite agronomic cultivars from South-eastern Asia and West and East Africa.

Initially a modest number of elite selections from advanced populations were crossed to selected shoot fly-resistant parents to develop populations combining pest resistance, yield, and quality. The population will be ready for the

Table 6. *Striga* plants per sorghum plant, *Striga* plants per plot, and laboratory germination index (Swarna = 100) of the 15 best Striga-resistant lines selected in field testing at Akola during rainy season 1976.

Entry	Source	*Striga* plants per sorghum plant	*Striga* plants per plot	*Striga* germination index[a]	Remarks
		(no)	(no)	(%)	
SRN 4841	Samaru, Nigeria	0.00	0.00	0.00	Resistant to *S. hermonthica*
IS 5603	India (farmers' type)	0.00	0.00	180.17	
23-4	Mohol, India (selection from Matdani x Bonganhilo)	0.00	0.00	88.46	
IS 2643 (BH4-1-4)	India	0.00	0.00	0.00	Resistant to 5. *asiatica*
IS 6942	Sudan	0.00	0.00	97.31	Resistant to S. *hermonthica*
SRN 1352	Samaru, Nigeria	0.01	0.25	6.92	Resistant to 5. *hermonthica*
IS 1464	India (farmers' type)	0.02	0.25	162.50	
N-13	Nandyal, India	0.02	0.25	100.10	Yellow pericarp
SRN 4310A	Samaru, Nigeria	0.02	0.25	5.98	Resistant to *S. hermonthica*
SRN 6788A	Samaru, Nigeria	0.02	0.50	106.68	Resistant to S. *hermonthica*
555	India (IS3687 x Aispuri)	0.03	0.50	0.00	
SRN 6838B	Samaru, Nigeria	0.05	0.75	64.65	Resistant to *S. hermonthica*
IS 5218	India (farmers' type)	0.05	1.00	98.38	
IS 8264	Uganda	0.06	1.25	104.56	Resistant to S. *hermonthica*
IS 1506	India (farmers' type)	0.08	1.50	93.80	
CSH-1		8.28	128.27	-	Check (field tests)
Swarna		-	-	100.00	Check (laboratory germination test)

[a]Reflects the number of seeds of *S. asiatica* germinated by the cultivar in the laboratory, expressed as a percentage of the number germinated by the check cultivar Swarna.

first yield test in postrainy season 1979. It is proposed to incorporate stem-borer and midge resistance into the same population.

Grain-grass Sorghums

Grain-grass sorghums are shorter, earlier, higher tillering, and smaller in the head than normal sorghums, and are intended for use in drought-prone areas where total rainfall is around 350 to 500 mm.

Improved grain-grass types are available from selections from crosses; a population is also being formed.

Testing under low fertility and high population density (450 000 plants/ha) took place

Table 7. The relationship between cultivar and germination, expressed as laboratory germination index (Swama = 100), of *Striga* spp. from five locations in India.

Cultivar	Source of *S. asiatica*					Source of *S. densiflora*	
	ICRISAT Center	Parbhani	Surat	Akola	Coimbatore	Surat	Coimbatore
IS 8315 x WABC 4072	0.00	0.00	0.00	0.00	0.87	26.41	0.00
IS 7191	1.43	0.00	1.53	0.00	6.33	191.24	0.00
IS 3962 x WABC 1022	0.27	1.34	0.00	0.00	0.00	32.03	0.00
IS 2404	0.00	0.00	0.00	0.00	0.00	21.44	0.00
S 1137	2.62	1.68	2.18	0.00	0.00	73.73	0.00
IS 7415	0.00	3.47	0.00	0.00	2.05	56.45	0.00
SRN-4310A	7.76	4.24	8.15	0.00	0.00	64.11	0.00
IS 7227	2.78	0.00	0.00	0.00	0.00	12.83	0.00
IS 2646	-	0.00	0.00	0.00	0.00	32.89	0.00
76K3-97	1.33	0.00	0.00	0.00	0.00	11.23	0.00
Framida	0.00	0.00	0.00	0.00	0.00	0.00	137.44
IS 7408	3.24	0.00	0.00	0.00	0.00	99.65	0.00
IS 3898	1.37	0.00	0.00	1.18	0.00	46.54	0.00
SRN-5192 (IS 4997)	0.00	8.16	2.26	-	-	0.00	-
SRN-6496 (IS 9674)	0.00	4.84	0.00	-	-	0.00	-
Swarna[a]	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[a] The number of *Striga* seeds germinated by each cultivar is expressed as a percentage of the number germinated by Swarna. With the *S. asiatica* seed collected from Coimbatore, for example, the number of seeds germinated by IS 7191 was 6.33 percent of the number germinated by Swarna.

during postrainy season 1976. One selection significantly outyielded the hybrid check, and eight significantly outyielded the better varietal check (Table 8). However, the hybrid and varietal checks were sown at the high population level, which inhibited their performance. Trials are now being conducted with grain-grass and grain sorghum types, each at their optimum population levels.

Identified sources of resistance to *Striga,* grain mold, shoot fly, stem borer, and midge have been crossed into grain-grass types. These crosses were evaluated in collaboration with entomologists and pathologists; 22 were identified as less susceptible to shoot fly and 8 less susceptible to *Striga.* Further crosses have been made to identify resistant sources.

Collaborative studies with the physiologists indicate that some grain-grass lines have drought tolerance and good recovery after release of stress. At ICRISAT Center, a plant population of 400000 to 700000 plants per hectare is optimum. Thirteen lines are being further evaluated for ratooning capability under dry-land conditions.

Physiology

Mechanical Resistance to *Striga*

In order to better understand the nature of mechanical resistance to *Striga,* we have undertaken studies of the mode of infection or invasion

Figure 6. An ICRISAT breeding nursery.

of the *Striga* haustorium and of the anatomy of the roots of sorghum cultivars showing mechanical resistance.

After the *Striga* seed germinates, the haustorium makes contact with the sorghum root and penetrates its cortex, distorting or rupturing the cortical cells. The haustorium pierces the endodermis and pericycle. The elongated cells of the haustorium rupture and the differentiating protoxylem strands establish vascular connection with the vascular bundle of the host root (Fig 7).

Resistance to *Striga* is correlated with the presence of thick-walled endodermal cells (and associated sclerenchyma tissue) in the pericycle and also the presence of silica crystals in these cells. Haustoria were observed to penetrate the cortex of resistant cultivars, but failed to advance past the endodermis into the vascular bundles, suggesting that the combined endodermis/pericycle formed a mechanical barrier (Fig 8). We are carrying out more-detailed studies in collaboration with the sorghum breeders and hope to further examine the role of the mechanical barrier in resistance, and to investigate its inheritance.

Table 8. **Yield data of selected grain-grass lines in postrainy season 1976 low-fertility trials at ICRISAT Center.**

Pedigree	Grain yield
	(kg/ha)
GC 497	1638
GC 198	1319
GC 421	1304
GC 522	1304
GC 318	1275
GC 50	1261
GC 489	1232
GC 478	1 188
GC 441	1 150
GC 529	1 145
GC 227	1 116
GC 152	1101
CSH-6 (Check)	1232
CSV-3 (Check)	913
CSV-4 (Check)	768

C.V. (%) = 28.85
L.S.D. (0.05) 2.41

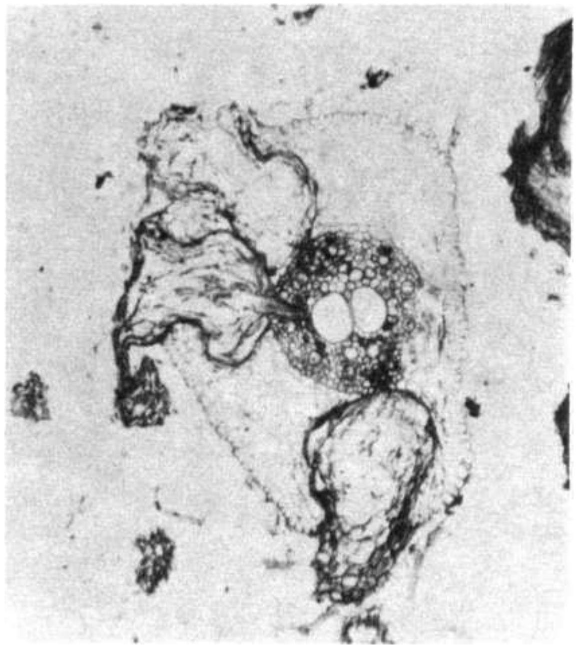


Figure 7. Infection of the root of a Striga-*susceptible cultivar by three* Striga *haustoria.*

Drought Resistance

We have completed two sets of experiments designed to evaluate the potential of controlled irrigation during the dry season for screening for drought resistance, one in the hot dry summer when atmospheric demand is most severe and the other in the cooler postrainy season. In both sets, irrigation was withheld during the panicle-formation stage (approximately 30 days before flowering) when the effects of stress on grain yields are greatest.

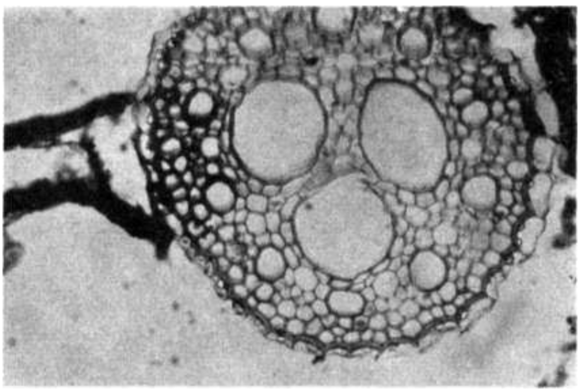
The severe stress resulted in a far larger reduction in total crop dry weight, grain yield, and grain numbers than did mild stress (Table 9). Additionally, growth was interrupted in a large number of cultivars during the period of severe stress, as indicated by differences in days to maturity between control (irrigated) and the stress treatments. This situation, observed in the hot dry season, was not present in the postrainy season. Independent of the stress effects, we observed significant seasonal differences in crop growth and yield components.

Grain yield in the presence of stress can be thought of as a function of the genetic yield potential in the absence of stress, a generalized effect of stress, and a specific *genotype* x *stress* interaction. These effects can be estimated in a simple linear regression model of yield in the presence of stress as a function of yield in the absence of stress, using the deviation of actual yield from predicted yield under stress to represent the interaction term. This deviation term provides a measure of the (relative) resistance or susceptibility of the individual cultivars to stress, i.e. a high positive deviation suggesting relative resistance and a large negative deviation indicating susceptibility.

Yields under the moderate stress conditions were observed to be closely related to yields in the absence of stress (Fig 9A), with the mean absolute deviation from predicted yield being only 9 percent of the predicted yield. This suggests that the mild stress conditions were not sufficient for the expression of genotype differences in response to stress. In the severe stress, however, deviations from predicted yield were much larger (Fig 9B) with the mean absolute deviation equal to 26 percent of the predicted yield and a range in deviations from —59 to +63 percent This provided the opportunity to tentatively identify, for use in future studies, a number of genotypes with possible different responses to stress.

We attempted unsuccessfully to correlate the results of genotype performance under mild and severe stress. The reasons for this failure are undergoing study, as there are several potential explanations, including the possible lack of expression of significant *genotype* x *stress* interaction in mild stress and the probability (as experienced with other crops) that *genotype* x *stress* interactions are very specific to a given set of environmental conditions. A solution is necessary before routine screening for drought-stress resistance can be confidently undertaken.

Figure 8. Failure of Striga *haustoria to penetrate the endodermis of the root of a* Striga-*resistant sorghum cultivar.*



Studies on Crop Growth and Yield

We analyzed data from a major study on growth and yield of 49 diverse genotypes. Overall correlations were established between grain yield and the following growth characteristics: seed number per panicle, seed weight, length of panicle formation (GS_2), and harvest index.

We selected, for more-detailed analysis, 15 genotypes with contrasting GS_2 and GS_3 (grain-filling) stages. Genotypes with a long GS_2 produced greater total dry weight, seed number, leaf number, and leaf area (Table 10). Types with a long GS_3 produced less vegetative growth, but had a much improved harvest index and grain weight to leaf-area ratio. Our most significant finding was that yield differences between the two groups of cultivars were not statistically different, indicating that both are capable of producing satisfactory yields. The long GS_2 type however, should have a greater yield potential based on its ability to produce greater seed numbers and greater leaf area to support grain

Table 9. Mean effects of artificial drought stress during the panicle-formation stage on sorghum yield and yield components.

Yield component	Control	Severe stress	Control	Mild stress
Time to maturity (days)	103	118	97	97
Total dry matter yield (ton/ha)	11.3	7.9	6.8	5.6
Grain yield (kg/ha)	2150	1230	2510	1940
Harvest index (%)	0.24	0.17	0.37	0.35
Grain number (1000/m^2)	12.9	7.2	10.3	8.3
100-seed weight (g)	22.7	19.1	33.1	30.0

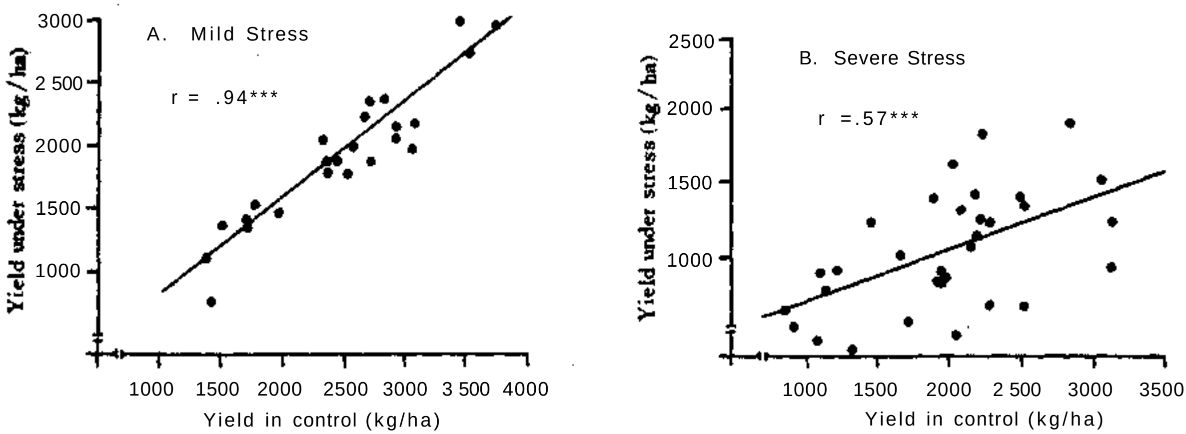


Figure 9. Relationships of sorghum yields under stress with yields in absence of stress.

filling. There is also a much better possibility to improve yields via improvements in harvest index (converting a greater percentage of the total dry matter produced into grain) in the long GS_2 types.

Entomology

Pest Assessment and Pest Populations

For the third season three standard sorghum cultivars-CSH-1, "Swarna," and Local (Pachajonna)-were planted at the break of the rainy season on a pesticide-free Vertisol area and detailed insect observations recorded throughout the season. Shoot-fly infestation was low in the early sown crop and 95 percent of the males bred from the crop were *Atherigona soccata.* A potentially important predatory mite, identified as *Abrolophus* sp., was discovered feeding on eggs and first-instar larvae of this pest. Attack by stem borer, *Chilo partellus,* was heavier than usual, and also earlier; however, little difference in damage was recorded between cultivars. At harvest time more larvae were present in CSH-1 than in the other cultivars, and larvae tended to be more numerous in harvested stalks, to persist longer, and to survive better in this cultivar. Midge attack was low.

We prepared a detailed list of insects and their parasites recorded from sorghum at ICRISAT Center; the list will be published.

Shoot-fly Taxonomy and Biology

Of seven species of shoot fly bred from sorghum, only *A. soccata* is important as a pest. Three additional alternative grass hosts of shoot fly were identified - *Cymbopogon caesius* (Nees) Stapf, *Echinocloa crusgalli* (Linn.) P. Beauv., and *Eragrostis japonica* (Thunb) Trin. Three other grass hosts, one of which appears to be of significance, remain unidentified. Shoot flies were also bred from wheat and *Sorghum halepense* (Linn.) Pers.; the latter is a potentially important carry-over host. In a study to determine if diapause occurs in the pupal stage, most pupae emerged at the expected time - but one took 10 weeks, indicating that extended development is possible.

Studies on the various shoot-fly species and alternative hosts confirmed prior observations that flies are highly discriminative in selection of a host plant. Although *A. oryzae* and *A.falcata* were dominant on grasses, the former clearly preferred *E. japonica* and *Digitaria adscendens* (H.B.K.) Henr. and the latter *Echinocloa colonum* (Linn.) Link and *E. crusgalli* (Reddy & Davies 1977). A total of 18 different species of shoot fly has been recovered from fields at ICRISAT Center-four of which are new to science.

Table 10. Comparison of characteristics of genotypes with long GS_3 and long GS_2.

Character	Mean (Sample size= 15) Long GS_3	Long GS_2	Difference in means* (GS_3-GS_2)
Grain weight (g/plant)	40.9	51.4	-10.5 NS
GS_1 (days)	32.1	34.0	-1.9 NS
GS_2 (days)	33.0	53.9	-20.9*
GS3 (days)	53.6	40.3	13.3*
Seed (number/panicle)	1030	1402	-372*
100-seed weight (g)	4.13	3.77	0.36 NS
Seed (no/GS_2 day)	31.2	26.3	4.9 NS
Seed weight (g/GS_3 day)	0.77	0.96	-0.19*
Plant height (cm)	183.0	229	-46.0*
Total dry weight (g/plant)	96.6	167.8	-71.2*
Harvest index (%)	42.5	32.2	10.3*
Grain/leaf ratio (g/cm^2)	5.7	3.5	2.2*
Stem weight/total weight (%)	24.4	34.2	-9.8*
Total leaves at flowering	13.7	17.5	-3.8*
Leaves produced in GS_2	4.30	8.3	-4.0*
Position of largest leaf (flag leaf = 1)	2.82	4.33	-1.51*
Area of upper leaves (cm^2)[b]	506	952	-446*

[a]NS, Not significant;*, Significant at 5 % level, according to Cochran-Cox t-test.
[b]Leaves above largest leaf, largest leaf included.

Use of fish-meal traps to assess the seasonal incidence of shoot fly revealed two peaks of activity - one in August/September and the other in December. Over the year approximately 12 times as many females as males were caught in the traps at 20 sites. Of a total of 21108 males caught, 51 percent were *A. soccata.* We recorded low catches in the summer months (Apr-Jun), and since they were usually female, identification by species was impossible.

Stem-borer Biology

In our study of alternative hosts of *Chilo partellus,* the insect was bred from cultivated sorghum, pearl millet, maize, and Setaria. Grass alternative host records included *Dinebra retroftexa* (Vahl) Panz., *Hetropogon contortus* (Linn.) P. Beauv, *Cymbopogon caesius, Chloris barbata* Sw., and *Sorghum halepense.*

As part of our intensified program on the stem-borer pheromone, observations were made on virgin females as attractant sources. Day-old females were highly attractive-up to 173 males being attracted to one female in a single night. The ability of virgin females to attract appeared to decline after about 3 days, but catches were obtained up to 10 days from exposure. Irrigation of fields boosted trap catches and this observation was used in screening studies.

We carried out several experiments using female pheromones synthesized at the Tropical

Products Institute, London. The major pheromone caught significantly more moths than all other treatments, and there was an indication that the minor pheromone was an inhibitor - since fewer moths were caught than with the virgin female and even fewer than in the "control" water traps (Fig 10). We recorded significant differences in catch over nights but this was not solely due to ageing of the pheromone, since peaks were recorded in the water traps also. The peaks appeared to be associated with irrigation of the experimental blocks or adjacent areas or with rain (Fig 11). In subsequent experiments in which we compared the ratios of major to minor pheromone with virgin females, six parts of major to one part minor was optimal for catch, but all pheromone traps caught fewer male moths than did the virgin females. The synthetic pheromones were active for up to 49 days.

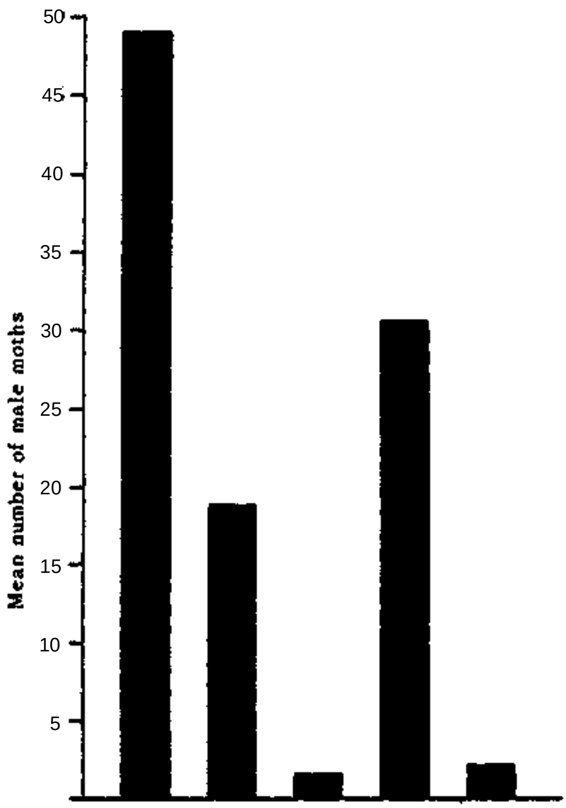


Figure 10. Mean daily catch of Chilo partellus *males on five treatments over 15 nights at ICRISAT Center (March 1977).*

Screening for Pest Resistance

Shoot fly. We screened a large amount of the sorghum germplasm for shoot-fly resistance, using the fish meal and interlard technique. Two groups of elite material which had previously performed well were submitted to high levels of attack using a grid system. IS 1054, 2146, 2162, 2312, 5604, 5604 x 23/2, 5613, 5622, and 5648 were confirmed as nonpreferred for oviposition. Lines recently collected from farmers' fields by germplasm botanists and untested IS lines were grown twice, and IS 1119, 5296, 5113, 2195, 5480, and 8311 were nonpreferred for oviposition. Taking subsequent dead heart and head production counts into consideration, IS 1119, 5480, 2176, and 2195 were selected for further investigation.

Lines showing some shoot-fly tolerance were grown in larger blocks at three scattered sites at ICRISAT Center. IS 1082, 2312, 4002, 4036, 4829, 5642 and derivatives IS 1082 x WABC 4062, IS 5642 x R 960, EN 3308, and EN 3362-1

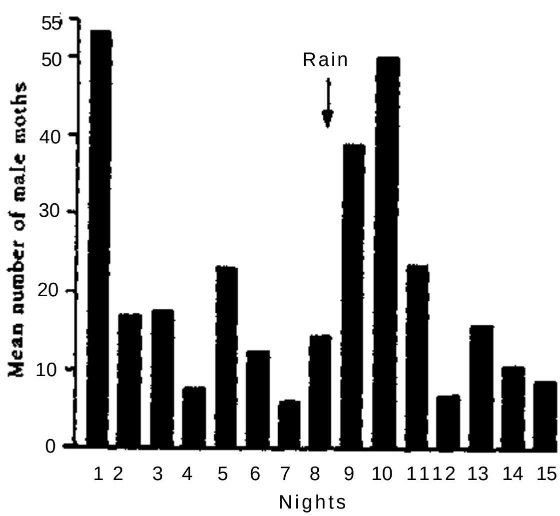


Figure 11. Mean nightly catch of Chilo partellus *over 15 nights in 15 traps at ICRISAT Center (March 1977).*

all performed well for shoot fly-none having more than 1 percent dead hearts. However they were moderately susceptible to *Chilo partellus* - the most resistant line was IS 4829, with a mean of 49 percent of the stems affected. Maximum head production per unit area was obtained from IS 4002, 4036, EN 3362-1, and EN 3308-the latter being extremely productive. The best grain yields were obtained from IS 4036 and EN 3308. The lowest number of larvae in stems at harvest was on IS 4002 (9 % of stems) and the highest was on IS 4829 (23 %). IS 1082 x WABC 4062 had 20 percent. More than 5 800 breeders' lines were scored for shoot-fly attack.

Stem Borer. Production of *Chilo* larvae, using an artificial diet, was sufficient to initiate artificial infestation studies on germplasm lines. Lines showing promise in two seasons of testing were E 302, E 303, BP 53, IS 1044, 1056, 1151, 2122, 2205, 4747, 4776, 4799, 4866, 5030, 5470, V-2-1-1-1, and V-2-1-1-2. In "grow out" trials of much of this material under high natural infestation conditions, E 303, 1044, 1151, and 5470 all had less than 30 percent damage compared to CSH-1 with 69 percent.

Midge. Studies on the damage, biology, and resistance to midge were intensified, but work was hampered by the low levels of attack at ICRISAT Center. Seventy-six lines suspected of having some resistance to midge were sown at Sillod and Selsoor with the cooperation of the Maharashtra Department of Agriculture. These preliminary trials indicated that SC 173 (IS 12664 *C),* SC 175 (IS 12666 C), SC 423 (IS 2579 C), SC 329 (IS 3574 C), SC 63 (IS 12573 C), and SGIRL-MR-1 should be further tested.

Other Studies

Some work was initiated on storage pests of sorghum as a preliminary to work on storage characteristics of sorghum cultivars. There were distinct differences in *Sitophilus oryzae* multiplication rates in CSH-1, "Swarna," and Local sorghums.

Our insecticide trials failed to elucidate reasons for the apparent failure to control *Atherigona soccata* with carbofuran, but did confirm that the insecticide was less effective than in previous use.

Pathology

The main objective of the sorghum pathology program is to minimize the possibility that improved high-yielding sorghums will be vulnerable to disease epidemics. To achieve this, stable broad-spectrum resistance must be located and incorporated into high-yielding genotypes.

Screening for Grain-mold Resistance

Short-cycle sorghums need resistance to grain mold as they often mature under wet conditions and produce grain with low market acceptability and poor viability, and may contain mammaliotoxic fungal-produced mycotoxins.

Seventeen fungal species in 11 genera were isolated from moldy sorghum grain. The most frequently isolated genera were *Fusarium, Curvularia, Tricothecium,* and *Olpitrichum,* in that order.

More than 5000 germplasm lines were inoculated with pathogenic isolates of *Fusarium semitectum* and *Curvularia lunata,* either singly or together, and then compared with noninoculated heads in the same row. Conditions in rainy season 1975 were favorable for mold development and only 90 lines with little or no mold were selected for further tests. Unfortunately in rainy season 1976, September and early October had but little rain and this was not conducive to profuse mold growth. However, mold development was sufficient for differentiation of low and high susceptibility; of 1421 lines tested, 33 were selected. The best material from 1975 was tested at several locations in the International Sorghum Grain Mold Nursery, discussed in a subsequent paragraph.

Screening for Downy Mildew, Leaf Diseases, and Stalk Rot

Work on diseases other than grain molds was focused on learning how to manage or promote them for screening of germplasm and breeding materials. The testing of stability of identified resistance was begun through the cooperative International Sorghum Disease Resistance Testing Program discussed below.

For sorghum downy mildew, use of early sown alternate rows to serve as an inoculum source shows promise for screening test material.

Sorghum grains infected with the anthracnose and leaf blight causal agents were placed in leaf whorls to promote these two diseases. The usefulness of this method will be further investigated for other nonobligate leaf pathogens.

Several methods and timings of inoculations with the charcoal-rot organism are under study and the technique selected will be used for screening breeders lines for susceptibility to this disease in subsequent seasons.

The International Sorghum Disease Resistance Testing Program (ISDRTP)

In collaboration with scientists from African and Asian countries, three nurseries-grain molds (ISGMN), leaf diseases (ISLDN), and downy mildew (ISDMN)-were widely tested. These international nurseries serve a vital function in that sorghum lines are exposed to many populations of the pathogens under a wide range of environmental conditions, which is essential for the identification of stable broad-spectrum resistance.

ISGMN. This nursery was sent to cooperators at 12 locations in six countries in Asia and West Africa. Very wet conditions during maturation in West Africa gave high levels of mold pressure, but in India the dryness in September and early October inhibited mold growth. Seventeen of the SO entries had mold ratings of 3 or less (in a 1-5 rating scale). The best entry across locations was E 35—1, a large white-seeded Zera Zera type from Ethiopia.

ISLDN. This nursery was sent to cooperators at nine locations in three countries in Asia and Africa. Two lines appeared to be resistant across locations to anthracnose, the most prevalent disease. Only one lowland site had sufficient leaf blight to adequately test for the disease, and here 2 lines were free and 26 showed only slight symptoms. There is a need to identify sites where more of the leaf diseases occur consistently, so that we can adequately test for stability of the resistance.

ISDMN. High levels of sorghum downy mildew occurred at three locations in southern India and two entries - QL-3 and SC 120-14- were free from systemic infection. Eleven entries had mean incidence values of less than S percent and maximum incidence values of less than 10 percent. We gratefully acknowledge the valuable assistance of our cooperators at Dharwar, Mysore, and Coimbatore in providing a good start to the ISDMN program. We need to locate sites in other parts of Asia, Africa, and southern USA where downy mildew occurs regularly.

Nutritional Quality

The newly acquired TAA (Technicon Auto Analyzer) was used for determination of protein after standardizing against the MKJ (micro-Kjeldahl) method. Close correlations (r = + 0.997) were obtained between the methods; the range of error was between —1.3 and +1.7 percent (Table 11).

Further refinements were made in the procedure for lysine estimation, using the DBC (dye-binding capacity) method. Use of a standard weight of one gram of sample and computing on the basis of 80 mg protein gave results in close agreement with those obtained using samples on a constant protein basis of 80 mg. This simplified method will be used in the future. A correlation of r = 0.89 was also obtained between the UIR (Udy Instrument Reading percentage transmission) on a one-gram sample and the MKJ method.

Based on these results the UIR/P values were correlated with the actual lysine values of samples, using 100 sorghum samples with a protein range of 7.3 to 19.1 percent and UIR/P values of

Table 11. Comparison of MKJ (micro-Kjeldahl) and TAA (Technicon Auto Analyzer) values of protein in sorghum grain.

Protein class	Samples	Average protein MKJ	Average protein TAA	Error
(%)	(no)	(%)	(%)	(%)
7.0-7.9	6	7.65	7.55	-1.3
8.0-8.9	10	8.36	8.36	0.0
9.0-9.9	9	9.53	9.49	-0.4
10.0-10.9	10	10.44	10.52	+0.8
11.0-11.9	7	11.56	11.59	+0.3
12.0-12.9	10	12.35	12.41	+ 0.5
13.0-13.9	11	13.31	13.34	+ 0.2
14.0-14.9	13	14.44	14.49	+0.4
15.0-15.9	7	15.36	15.59	+ 1.5
16.0-16.9	10	16.44	16.38	-0.4
17.0-17.9	4	17.28	17.20	-0.5
18.0-18.9	2	18.05	18.35	+ 1.7
19.0-19.5	2	19.05	19.15	+0.5

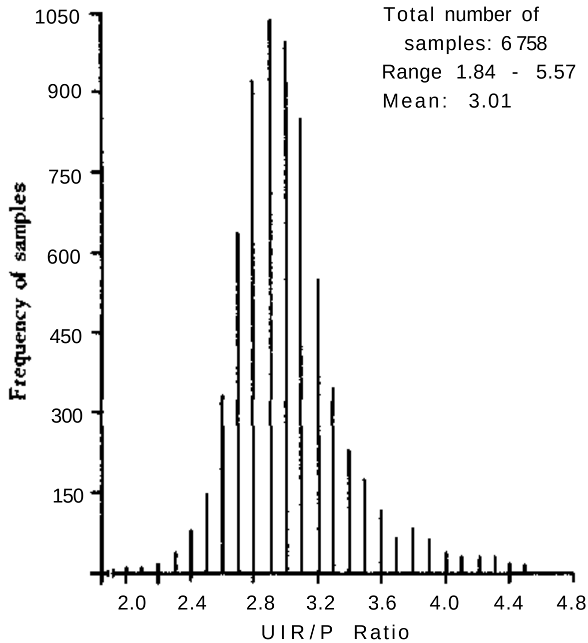


Figure 12. Range of estimated lysine content in 6 758 sorghum samples analyzed at ICRISAT.

between 2.07 and 4.57. A close correlation (r = +0.93) was obtained between UIR/P and lysine concentration (g/100 g protein) and a regression equation calculated. Further work is under way to determine whether this can be used with confidence as a reliable method for prediction of lysine values.

A range of 100 germplasm samples of eight types (with luster, with subcoat, completely corneous, almost corneous, intermediate, almost floury, completely floury, and with waxy endosperm) were analyzed in subgroups, taking into account color-white through yellow to brown, red to purple. The 100-seed weight (corrected for moisture) ranged from 1.16 to 4.64 g, protein from 9.3 to 16.9 percent, starch from 72.8 to 83.6 percent, soluble sugars from 0.8 to 1.8 percent, fat from 2.2 to 5.5 percent, fiber from 1.0 to 2.3 percent, and ash from 1.2 to 2.2 percent.

Routine screening of 6 758 sorghum samples for protein and basic amino acids using the TAA and the DBC methods respectively gave a range of6.0 to 21.1 percent (mean 12.1 %) protein. The UIR/P ratio was 1.84 to 5.57 (mean 3.01) (see Fig 12).

Microbiology

Efforts are concentrated on developing an assay method for screening large numbers of field-grown plants for nitrogenase activity of bacteria associated with their roots. The assay is based on the reduction of acetylene to ethylene by the nitrogenase enzyme. With as little soil disturbance as possible, soil cores containing plant roots are taken in metal cylinders (15-cm diameter, 22-cm length) and incubated in sealed 6-liter plastic vessels under an atmosphere of ca. 15 percent acetylene in air. Gas samples are taken 17 and 24 hours later for gas chromatographic analysis of ethylene production.

Cores in an atmosphere without added acetylene produce little ethylene. It is assumed that acetylene-induced ethylene production is due to reduction of acetylene by nitrogen-fixing bacteria and not due to inhibition by acetylene of the oxidation of endogenous soil-produced ethylene. For estimating the amount of nitrogen fixed, a conversion ratio of 3 C_2H_4 is equivalent to 1 N_2 is used.

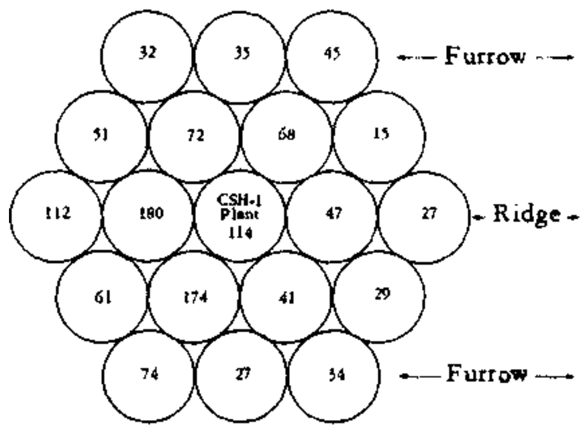
Using this assay, sorghum lines grown under low-fertility (20 kg N, 9 kg P fertilizer/ha) conditions on Alfisol at ICRISAT Center were screened for nitrogenase activity in the 1976 rainy season and in the 1976-1977 postrainy season, as were lines grown at Bhavanisagar in southern India during the hot dry season of 1977. These lines included landrace cultivars from different locations and environments, crosses and selections which performed well under both high- and low-fertility conditions at ICRISAT Center, hybrids and their parents, grain-grass types, fodder types, and related *Sorghum* species. Of more than 347 entries, 110-including some members of all of these groups - had nitrogenase activity greater than 50 μ g N/core per day. There were large differences between cultivars, even though considerable variation in activity occurred from plant to plant. For example, the active line IS 2333 from Sudan had a mean activity of 325 μ g N/core per day (range 127 to 534 μ g N) when assayed during the grain-filling stage. This plant-to-plant variability does not seem to be related to differences in dry weight of plant top or root. Some lines supported no more activity than did soil cores without roots, but 26 lines had a mean activity greater than 100 *p* g N/core per day.

Activity continued well into the grain-filling stage and was usually greatest after flowering. There was no activity in the postrainy season until the beginning of March. This was probably due to the cool (night?) temperatures earlier in the season. The nitrogen-fixing bacteria are closely associated with the roots, with little activity in cores with soil only. Activity decreases as soils dry, although plants do not show wilt symptoms.

Ninety-four entries were also grown at Bhavanisagar during the hot dry summer season. There were again significant differences between lines when assayed during the grain-filling stage. The line IS 2980 from Ethiopia had the largest mean activity of 127 μ g N/core per day (range 12 to 351 μ g N). A further 16 lines had mean activities greater than 50 *p* g N/core per day.

Some lines, including several grain-grass types, were consistently active in all three growing seasons. Sudan grass and *Sorghum halepense* were also active.

The activity of sorghum roots after flowering extends laterally at least 30 cm beyond the single core over the crown of the plant. Figure 13 shows one experiment, assayed 14 Apr 1977, where the core with the crown had 114 μ g N/core per day while activity in surrounding cores ranged from 15 to 180 *p* g N/core per day.



Soil alone: 22 μ g N/core per day
Soil plus loose roots: 72 μ g N/core per day

Figure 13. Nitrogenase activity (pgN/core per day) of soil cores taken over the crown of sorghum CSH-1 and in the surrounding unplanted area. Activity measured in the core is represented by the number within the circle.

Looking Ahead in Sorghum Improvement

Germplasm. The collection will be maintained and lines purified and grown out as necessary to ensure conservation of genetic stock. Lines will be characterized using descriptors recommended by IBPGR, and ICS numbers will be assigned to new collections. Introgression work will continue, as will screening in collaboration with other disciplines: pathology, microbiology, and entomology.

Breeding. We aim to bring together and strengthen traits for improved yield and yield stability, and to provide source material on an expanding basis to sorghum breeders in national programs. This will involve incorporating resistances - by conventional and population breeding methods-to diseases, pests, and drought in our advanced breeding lines. It will, of course, be a cooperative effort with ICRISAT colleagues in various disciplines including pathology, entomology, and physiology.

Increasing emphasis will be placed on exchange and testing of breeding material with ICRISAT cooperating centers and cooperators throughout the SAT. A particular aim will be to extend work on screening for the African *Striga* species and strains.

Physiology. Studies on the dynamics and determinants of growth and yields in various genotypes will be continued. We will expand greatly the work on drought resistance - initially by developing suitable screening techniques and subsequently by investigating the nature of resistance and susceptibility - so that breeders can select positively for favorable traits. We intend to continue studies on seedling vigor and crop establishment, and will conduct collaborative research with the breeders and entomologists for selection criteria and the physiological and morphological aspects of pest and *Striga* resistance.

Entomology. The emphasis of our screening program will move from identification of sources of borer and shoot-fly resistance in the germplasm to the screening of lines produced in the breeding program. In the work with midge, development and use of a screening method will have priority.

Observations on the biology of the major pest species will continue and comparisons will be made between the pest complex at ICRISAT Center and elsewhere in the SAT. Information coming from our cooperating programs is essential for this. Overseas testing will be intensified.

The work on *Chilo* pheromone will enter a phase of attempting to assess whether pheromones can be used for control of this pest as well as for sampling of populations.

Pathology. Work will continue on the development of improved screening procedures for the main sorghum diseases - grain molds, leaf diseases, downy mildew, and stalk rots-and the utilization of the techniques in the location and incorporation of stable resistance in high-yielding lines.

The multilocational disease nursery program, conducted in cooperation with colleagues in national and regional programs throughout the SAT, will enable the identification of stable resistance and will provide a means of giving local programs material with much broader resistance than could have been identified from within the local program.

Nutritional quality. On completion of the standardization of methods for protein estimation and modification of the screening method for lysine, we will be able to handle a larger volume of samples for the breeding program. More work will be focussed on other important areas such as cooking and keeping quality, and on digestibility of sorghum.

Microbiology. The aim of this program is to determine whether nitrogen-fixing bacteria closely associated with sorghum roots have the potential for reducing the amount of nitrogen fertilizer required by sorghum crop. We will improve the techniques for measuring the amount of nitrogen fixation associated with sorghum cultivars and embark on an expanded program to identify sorghum lines with enhanced nitrogen-fixing activity.

PEARL MILLET

Pearl Millet

Germplasm

We have now received 5048 accessions which include all the available IP (Indian Pennisetum) entries and 351 added this year from parts of India and West Africa. The great majority of these accessions are landraces collected from farmers' fields, but unfortunately most of the older collections have been excessively selfed or contaminated. The recently appointed millet botanist has therefore been determining which members of the IP collection (including duplicates) still agree with the catalog, and devising practical methods of maintaining variability within the recent accessions.

A total of 4 317 entries were sown, standard observations recorded, and selfed seed retained from some. Of 2 250 IP lines studied, 1075 agreed with the catalog description. A further 800 exhibited useful traits and were also kept. Twenty-six lines were selected for use in the breeding program. High levels of rust infection occurred in the germplasm plots and 128 rust-free plants were identified. Allowing plants sown in hills to intercross under large bags, coupled with long-term storage facilities, appears to be a feasible way of maintaining collected variability. The postrainy season, where days are short, will be the most "neutral" season in which to do this; seed quality will also be best at this time.

During the year seeds of 1 540 accessions were supplied in response to requests (Table 12).

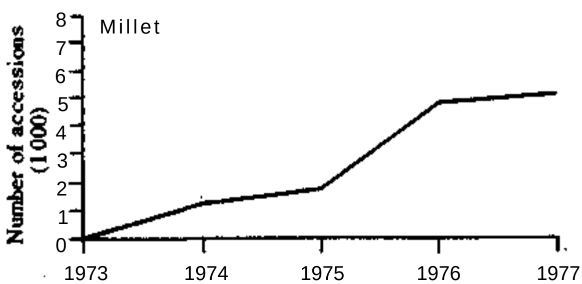


Figure 14. Pearl millet germplasm accessions at ICRISAT Center.

Breeding

Breeding continued with two main approaches (recurrent selection in composites, and variety crosses) to produce varieties, hybrids, and inbreds for ICRISAT and international yield trials, as well as an array of breeding material for distribution to breeders (Fig 16). The development by ICRISAT cereals pathologists of an effective field technique using infector rows now allows thousands of entries to be screened against downy mildew, in both the rainy and postrainy seasons.

Source Material

The working collection, consisting of 340 lines from diverse geographical regions having characteristics of agronomic interest, when grown over several seasons and locations indicated existence of an enormous variability for daylength reaction, disease reaction, grain size, drought tolerance, protein content, and restoration ability on the three cytoplasmic male-sterile systems. Data gathered on this collection, seed of which is available, has been sent for processing to the Information Sciences/Genetic Resources Program located at the University of Colorado, USA. As further germplasm accessions, including the intermediate forms (shibras) from Africa, are acquired at ICRISAT Center, the working collection will be expanded.

In addition to the existing five source populations in this project (Casady, Nigerian Dwarf, Mokwa-maiwa, Maiwa, and Ex-Bornu) we have added four dwarf (D_2) populations from IRAT, West Africa.

These populations (Table 13) are being improved by progeny evaluation and crosses have been made with good progenies to male steriles; to move desirable characteristics into more agronomically advanced backgrounds, crosses have been made to elite material.

Downy mildew-resistant lines have been identified for recombination in the Casady and Nigerian dwarf populations, each crossed onto male steriles.

Table 12. Millet germplasm lines supplied to research agencies in India and other nations during 1976-1977.

Institution	Location	Entries
INDIA:		
Agricultural Research Station	Anantapur, A.P.	60
Millet Research Station of Lam	Guntur, A.P.	62
M.S. University	Baroda, Gujarat	4
Haryana Agricultural University	Hissar, Haryana	2
National Dairy Research Institute	Karnal, Haryana	94
Punjabrao Krishi Vidyapeeth	Akola, Maharashtra	7
All-India Coordinated Millet Improvement Project	Rahuri, Maharashtra	330
Mahatma Phule Krishi Vidyapeeth	Rahuri, Maharashtra	12
Indian Agricultural Research Institute	New Delhi	2
Punjab Agricultural University	Ludhiana, Punjab	96
Agricultural Research Station of Durgapura	Jaipur, Rajasthan	80
Central Arid Zone Research Institute	Jodhpur, Rajasthan	32
University of Jodhpur	Jodhpur, Rajasthan	12
Tamil Nadu Agricultural University	Coimbatore, Tamil Nadu	41
Chandra Shekhar Azad University of Agriculture and Technology	Kanpur, U.P.	8
Banaras Hindu University	Varanasi, U.P.	9
OTHER NATIONS:		
National Research Council	Saskatoon, Canada	22
Mr. Guitierrez	Palmira, Colombia	10
Chinese Academy of Agricultural and Forestry Sciences	Peking, People's Republic of China	12
Afdeltng for Dyrefysiologi Biokem.	Denmark	15
UNDP	Addis Ababa, Ethiopia	1
College of Agriculture, University of Ethiopia	Debre Zeit, Ethiopia	8
Port Dauphin. S.A.	Haiti	4
Agriculture Research Centre	Tripoli, Libya	14
Kasinthula Research Station	Chikwawa, Malawi	65
CIMMYT	Mexico	30
USAID, Area Development Office	Niamey, Niger	114
University of Ibadan	Ibadan, Nigeria	62
Institute of Agricultural Research	Samaru, Nigeria	969
USAID/USDA	Islamabad, Pakistan	449
CNRA	Bambey, Senegal	376
Plant Breeding Institute	Cambridge, United Kingdom	21
University College of North Wales	Bangor, United Kingdom	5
Fundacion Servicio Para el Agricultor	Venezuela	18
Mennonite Central Committee	Kinshasa, Zaire	10

Figure 15. Cluster bagging and selfing to maintain pearl millet germplasm.

The landrace population Ex-Bornu from Nigeria has shown wide adaptability, good yields, and disease resistance in many trials. Seventeen good S_3's have been identified and crossed in diallel to choose entries for a synthetic.

Mokwa-maiwa and Maiwa are highly photosensitive but appear to carry good downy mildew resistance and seed-weathering resistance. S_1's of these populations have been crossed to Ligui from Chad, which is very early and photoinsensitive. In the F_2's, grown in the summer season of lengthening days, photoinsensitive selections with maiwa vegetative characters were made.

The four IRAT synthetics are dwarf, very leafy, and relatively late maturing, but with excellent head size. Numerous progenies have been test-crossed both to male steriles and to established inbreds from our variety cross project. A total 106 lines from 3/4 Souna and 3/4 Ex-Bornu remained disease-free in an initial screening for DM (downy mildew) resistance. Using artificial inoculation, a further 86 remained free of smut, and 12 free of ergot.

Finally in this source material project, which represents an intermediate stage between germplasm and leading breeding material, we are reconstituting our "dwarf" nursery of inbred lines. Of these, 280 originated from the Jamnagar breeding program and exhibit extreme advances in plant habit.

Composite Breeding

Fourteen composites are being improved by intrapopulation methods to generate experimen-

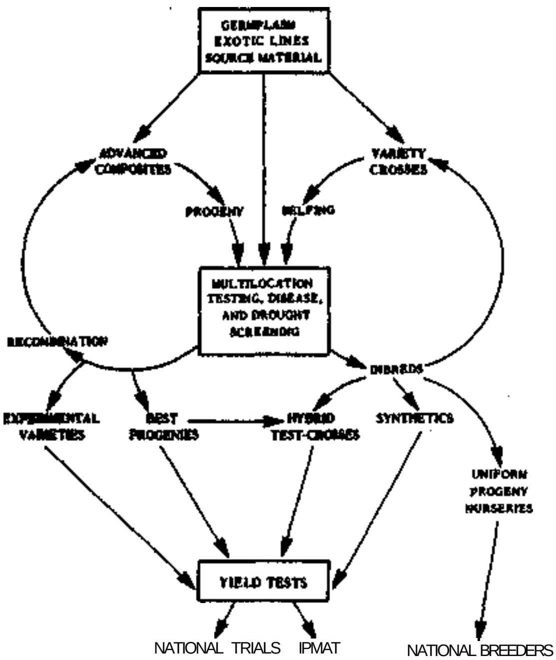


Figure 16. The pearl millet breeding program at ICRISAT.

tal varieties and best progenies for variety yield tests (Fig 17). In 1976 two cycles of selection were completed on four composites, the first cycle on nine more, and the last is undergoing random mating prior to the commencement of recurrent selection. Selection is effected through testing between 225 and 315 progenies at three or more locations with one replication in the DM nursery. Seed for recombination is taken only from plants remaining disease-free in this nursery. The selection differential obtained for the mean grain yield of the progeny selected for recombination has been about 32 percent, and 25 to 30 progeny are kept per composite.

Yield tests, conducted on several sites in 1976 in India, included 22 experimental varieties, 81 best progenies, and 7 C_0 vs. C_1 composite bulks produced as a result of 1975 progeny tests. Four experimental varieties-WC-C75, IVS-A75, SSC-C75, and MC-C75 - gave yields equal to the hybrid check PHB 14 (2070 kg/ha) with better downy mildew resistance. WC-C75 was also successful in AICMIP trials and has been selected for advanced testing.

Table 13. New source populations from IRAT in West Africa.

Population	Country of origin	Description
3/4 Souna (IRAT P. 10)	Senegal	Obtained by crossing the local selection "Souna" 2 to a D_2 dwarf source. Selection for resistance to downy mildew and smut and for good agronomic characters.
3/4 Ex-Bornu (IRAT P. 16)	Niger	Developed by crossing Nain 1/2 Souna x Ex-Bornu. Improved Indian germplasm and D_2 gene were also included. Resistant to downy mildew and smut.
3/4 Hainei-Khirei (IRAT P. 15)	Niger	Obtained by crossing Nain 1/2 Souna x Selections of variety P_3 Kolo (Zongo x HK) and Hainei-Khirei. To this were added germplasm from Senegal, India, and the D_2 gene. Resistant to downy mildew and smut.
Saria Synthetic (IRAT P. 8)	Upper Volta	Resulted from six best lines selected in the segregating generations of crosses involving local lines in 1971. Resistant to downy mildew.

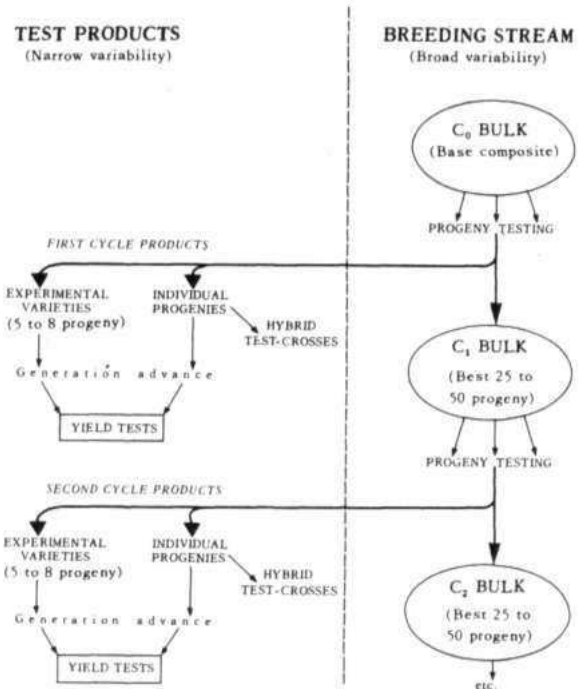


Figure 17. Generalized scheme for intrapopulation improvement in pearl millet at ICRISAT Center.

Individual best progenies from good composites increased by sibbing showed yield increases of up to 25 percent more than the parent composite and equalled the yield of the new AICMIP hybrid BK 560-230.

Though the difference was not statistically significant, an average of 5.3 percent yield gain was recorded in the comparison of C_0 to C_1 bulks in seven composites - the best being 13 percent. Reductions in height and increases in downy mildew resistance were obtained. Evidence from the next cycle (C_2) of progeny testing in these composites showed no loss in variability for yield, indicating that continued gains may be expected. This implies that future improvements will be reflected in subsequent experimental varieties.

One further composite is to be added to this project - an Elite Composite to be made of not more than 20 good tested diverse entries.

Reciprocal recurrent selection (inerpopulation improvement) has commenced, primarily

Figure 18. Multiplication plot of an experimental pearl millet variety at ICRISAT Center.

for the production of hybrids, on one complementary pair-IB and IR. Parents of 23 reciprocal full sibs were selected for recombination from the 1976 composite progeny tests where the selection differential was 24.5 percent. The individual hybrid pairs will be developed and evaluated as potential parents.

A diallel of 16 composites (parents and F_1's, excluding reciprocals) was tested in rainy season 1976 in two environments (high fertility and low fertility) at ICRISAT Center. The data were analyzed according to Gardner and Eberhart, as well as by Griffing's model. Combining-ability analysis indicate that the additive type of gene action played a predominant role in the determination of grain yield. Based on parental means, composite cross performance, heterosis, and the specific heterosis effect, one pair of complementary populations, Serere Composite 2(M) x Nigerian Composite, were identified for inclusion in this project. These two populations will be improved simultaneously by reciprocal recurrent selection using an inbred tester drawn from each population.

Comparison of Population Improvement Methods

This project was started in 1976 with the objective of comparing the selection efficiency of different recurrent selection methods. These methods are S_2 progeny selection (S_2PS), full-sib progeny selection (FSPS), recurrent restricted phenotypic selection (RRPS), and gridded mass selection (GMS). One good composite having wide genetic variability for important characters, the World Composite, was chosen for this study. The first cycle of FSPS, RRPS, and GMS was planted in the 1976 rainy season (July-Oct) while for the S_2PS system half-sibs and S_1's were grown during rainy season 1976 and the hot dry season (Feb-May) of 1977, respectively. First cycle of S_2PS and second cycles of FSPS, RRPS, and GMS will be grown in rainy season 1977. These procedures will be compared initially during 1978, but the final comparison will be made only after completing three cycles of S_2PS and the six cycles of the other recurrent selection methods.

Variety Crosses and Synthetics

This project aims to produce improved inbred or partially inbred lines derived by crossing complementary inbreds or varieties and making pedigree selections for two or three generations till a degree of uniformity is attained. The lines so produced are tested for use in synthetics, as potential hybrid parents, and for performance *per se.* They fill an important function in readily supplying a range of useful clear-cut variability to cooperating breeders.

The pedigree lines produced are also reviewed for further intercrossing. A computer program, using data from a standard set of descriptors

Figure 19. Pearl millet progenies derived from recurrent selection.

taken on potential parents, is being developed to ensure that the best crosses will be made.

In rainy season 1976, 525 new F_1's and 1000 F_2's were grown. The best selections from these were advanced in the 1977 hot dry season nursery where 266 superior F_3's and 126 F_4's were identified for the 1977 Uniform Nurseries. The remaining 1976 selections will be grown in rainy season 1977.

From more advanced lines, 48 progenies-mostly of African x Indian parentage - were chosen after intense selection for tillering (either one or many synchronous tillers), disease resistance, seed setting, and yield potential for entry into 1977 replicated yield trials; these lines, in nursery form, have also been supplied to 30 breeders in the SAT.

Ninety inbreds were tested in two yield trials at several locations in 1976. In both trials, a few inbreds gave yields equal to the hybrid check PHB 14. In Trial 1, grown at Bambey, Senegal, and at three Indian locations, three inbreds showed low levels of downy mildew incidence, besides yields equal to the check (Table 14). If the general relationship between inbred and hybrid yield levels holds true, then good inbred lines *per se* can be expected to produce better hybrids or synthetics. High inbred yield levels are also desirable in hybrid seed parents.

Three synthetics were generated from good inbreds and tested in IPMAT-2 (see International Cooperation) in 1976. One of these (SYN 7601, composed of six lines) showed some potential, but will require some refinement before release because it exhibited more phenotypic variability than is acceptable.

Hybrids

Three systems of cytoplasmic male sterility are being used to produce high-yielding disease-resistant hybrids.

Potential hybrid parents are developed in both the Variety Cross and Population Improvement projects and pass through three stages. Initially test-crosses are evaluated in single plots at ICRISAT Center, where most have to be discarded because of incomplete pollen shedding. Agronomically satisfactory fertile crosses move to the second stage —a replicated trial at several locations, including the DM nursery. Those surviving reach the third stage of wider national and international testing (Fig 20).

Table 14. Grain yields and downy mildew incidence of selected inbreds in PMIT 1,1976.

	Grain yield			Increase above PHB-14	DM incidence	
	ICRISAT Center[a]	Bambey, Senegal	Mean[b]		ICRISAT Center	Bambey, Senegal
	(kg/ha)			(%)	(%)	(%)
Souna D_2 x Ex-Bornu-161	3675	2190	2649	19	1.6	0.0
T 166-2 x 700594	3184	2507	2344	6	1.4	11.3
700638 xSC3(M)-17-1-2	3647	1853	2264	2	1.4	1.3
PHB 14[c]	3475	1657	2220	-	2.5	13.7
Mean (46 entries)	2424	1619	1671	-25	NA[d]	NA
	±396	±262	±330			
L.S.D. (0.05)	1110	735	752			

[a]The plots at ICRISAT Center had received 80 kg P_2O_5 and 150 kg N per ha.
[b]Mean yield over four locations.
[c]Highest-yielding check.
[d]Not averaged.

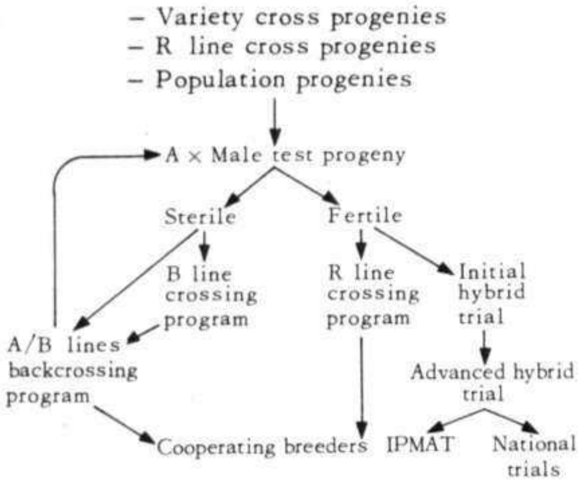


Figure 20. Flow of genetic material through the ICRISAT pearl millet hybrid program.

Parents found to be good maintainers are developed into A/B pairs. Crosses have been made between existing B-lines and between B-lines and sources of DM resistance to generate new seed parents. F_3's from these crosses have been selected for testing in India and Africa in 1977. Similarly, good R lines have been intercrossed to generate new pollen parents.

In 1976, 5054A, 5141A, 111A, MS75A, $239D_2A$, and 67A were used as seed parents in producing hybrids tested in three third-stage hybrid trials (PMHT 1, 2, and 3, divided on a height basis) and one second-stage trial (PMHT 4) conducted in rainy season 1976. Restorer lines originated variously from India, Africa, ICRISAT composite progenies, and newly developed progenies from Indian x African crosses.

Figure 21. Developing new pearl millet hybrids at ICRISAT Center.

Six hybrids in PMHT 1 yielded on average more than the best check, BK 560-230 (2420 kg/ha) (Table 15). Acceptable levels of resistance to downy mildew-both in India and at Kano, Nigeria - were associated with high-yield potential over environments in two hybrids - ICH 118 (2847 kg/ha) and ICH 117 (2540 kg/ha). In hybrid trial 2 (PMHT 2), four hybrids (ICH 128, ICH 129, ICH 126 and ICH 143) produced more than the yield of BK 560-230 (2702 kg/ha). The restorers of ICH 128 and ICH 129 were exotic and, in the case of ICH 129, the male parent was a population received from Serere, Uganda. PHB 12, from Ludhiana, India, gave the highest yield (2880 kg/ha) in PMHT 3; this was 15 percent more than the trial mean yield, and was closely followed by BK 560-230 (2 857 kg/ha) and ICH 162 (2735 kg/ha). In PMHT 4, two progenies (EC 298-2 and EC 298-3) from the Population Improvement project produced desirable hybrids in combination with 5141A and 111A.

Seed parents 67A, 111 A, and 5054A all produced high-yielding hybrids and those with 111A were less susceptible to downy mildew. In terms of yield alone, equally good hybrids can be made using as pollinators inbred lines, varieties, composite progenies, or populations. Tests in India classed most hybrids in trial PMHT 1 as DM resistant, but the trial at Kano revealed that - except for ICH 118, ICH 117, PHB 14, and ICH 119 - this resistance was location specific (Indian sites only). All hybrids resistant at Kano had 111A as the female parent while all the pollen parents were of African origin.

Table 15. Grain yields and downy mildew incidence of selected hybrids in PMHT 1 (1976).

		Grain yield				DM incidence	
Hybird	Pedigree	ICRISAT Center[a]	Kano, Nigeria	Mean[b]	Increase above mean[c]	ICRISAT Center Disease Nursery	Kano, Nigeria
		(kg/ha)			(%)	<%)	(%)
ICH 110	5054A x SC3(M)-1	3 803	1305	2895	32	2.2	87.8
ICH 118	111A x Souna B	3480	2416	2847	30	9.2	2.3
ICH 117	111A x 1/2HK	3271	1875	2540	16	5.3	23.8
ICH 116	111A x WC 3-7	3073	1903	2531	15	9.7	60.5
ICH 115	111lA x 700787	3002	1514	2528	15	5.4	34.9
ICH 114	5054A x 13092	3002	1153	2480	13	2.3	75.7
BK 560-230	5141A x K560-D230	3 294	1055	2420	10	2.6	73.0
PHB 14	111A x PIB 228	2701	1305	2387	9	4.7	31.3
ICH 119	111A x R 2591-30	2783	1264	2335	6	4.7	15.4
Mean (25 hybrids)		2789 ±274	984 ±217	2193 ±312	-	7.5	71.1
L.S.D. (0.05)		771	610	704			

a Received 80 kg P_2O_5 and 150 kg N per ha.
b Mean yield over all test environments.
c Increase above mean yield over all locations.

Table 16. Performance of the five highest-yielding entries over 30 locations in IPMAT-2,1976.

Entry	Pedigree	Time to 50% flowering	Height[a]	Grain yield	Increase[b]
		(days)	(cm)	(kg/ha)	(%)
ICH 105	5054A x B 282	51	164	2389	27
ICH 13	5071A x J 1188	54	189	2 345	25
BK 560-230	5141A x K560-D230	50	173	2281	22
ICH 108	5054A x Serere 2A-9	47	168	2178	16
ICH 107	111A x SC2(M)	50	186	2113	13
Local check (average)		51	178	1934	3
Mean over locations		52	183	1876	-

[a]Mean of 26 locations.
[b] Above mean yield over locations.

Table 17. Grain yields of the three ICRISAT entries and the highest-yielding check, over 32 locations, in the 30-entry AICMIP Advanced Yield Trial III, 1976.

Entry	Grain yield
	(kg/ha)
BK 560~230[a]	2270
ICH 105	2240
ICH 106	2060
ICH 107	1780
Mean of 30 entries	1990

[a]Check, ranked first.

The four ICRISAT hybrids tested in 1976 in IPMAT-2 all performed well (in comparison with commercial hybrid BK 560) at most locations (Table 16). ICH 105 and ICH 13 produced 27 and 25 percent more than the mean yield over 30 locations. All entries in Table 16 were relatively resistant to downy mildew in India, but very susceptible in certain West African locations. ICH 105, for example, had the lowest mean DM severity score over all Indian locations but was extremely susceptible at Samaru, Nigeria and at Maradi, Niger. This type of reaction indicates a location-specific resistance of potentially limited usefulness.

The All-India Coordinated Millet Improvement Project (AICMIP) tested three ICRISAT hybrids during 1976 in its Advanced Yield Trial III for limited-moisture conditions. ICH 105 (5054A x B 282) ranked second in yield (2 240 kg/ha) averaged over trials conducted at 32 locations in ten states of India (Table 17). This hybrid is being reevaluated in 1977 by the AICMIP in advanced trials, while a further three hybrids (ICH 110-5054A x SC3(M)-1, ICH 118-111A x Souna B, and ICH 190-111A x EC 298) were accepted into initial trials.

A further 2659 test crosses were initially evaluated at ICRISAT Center in rainy season 1976. Of these, 109 involving 111A, 5054A, and 5141A were retained for second-stage testing.

International Cooperation

Network of Breeding Centers

Five millet breeders are now on station in ICRISAT's African program-in Senegal, Upper Volta, Niger, Nigeria, and Sudan. In India, ICRISAT breeders also operate cooperative breeding nurseries in the north (at Hissar) and the south (at Bhavanisagar) and work with scientists in the AICMIP. Between India and West Africa, the main flow of early generation breeding material is between ICRISAT and Kamboinse in Upper Volta. Other research programs in Central and West Africa will draw mainly on Kamboinse for breeding material, but will participate in cooperative multilocational yield trials. ICRISAT and Indian breeders are now cooperating in coordinated composite progeny trials, enabling the breeders to select good progeny *in situ,* while contributing to the overall improvement of the composite.

International Trials

The Second International Pearl Millet Adaptation Trial (IPMAT-2) of 21 entries comprising experimental and commercial hybrids, varieties, and populations from several origins was sent out to 50 locations in 19 countries in 1976. Results were received from 32 locations (of which 30 could be used) in 11 countries. The average grain yield for the trial over these locations was 1 876 kg/ha, highest (4221 kg/ha) at Serere, Uganda and lowest (804 kg/ha) at Anand, India (Table 18). At only 10 locations did the local check or a commercial hybrid give the highest yield. Among the hybrids, ICH 105, ICH 13, and BK 560-230 gave 27, 25 and 21 percent more yield over the grand mean, while WC-C75 was the best of the seven experimental varieties and populations. The mean yield of the local check was near to the grand mean yield over locations.

Under the high DM pressure in West Africa, Ex-Bornu, WC-C75, NC-S75, and PHB 14 were the least susceptible. *Genotype* x *environment* interaction was strong for many entries but ICH 13, ICH 107, PHB 14, and WC-C75 combined high yield averages with good stability of yield.

Three hybrids and one experimental variety were entered in the 1976 AICMIP National Yield trials conducted over 32 and 16 locations in India, respectively. ICH 105 came second overall (2240 against 2270 kg/ha) in the hybrid trial while WC-C75 came fifth (1 490 against 1 530 kg/ha) in the varieties/composites trial, but gave the highest fodder yield. Both were selected for advanced testing.

Table 18. Mean yield performance of IPMAT-2 entries over 30 locations in the SAT, 1976.

Entry	Grain yield	Increase/decrease over mean yield over locations
	(kg/ha)	(%)
ICH 105	2389	+ 27.34
ICH 13	2345	+ 25.00
BK 560	2281	+ 21.58
ICH 108	2178	+16.09
ICH 107	2113	+ 12.63
PHB 14	2084	+ 11.08
WC-C75	2074	+ 10.55
Ex-Bornu	2055	+ 9.54
Syn. 7601	1980	+ 5.54
MC-S75	1945	+ 3.67
Local check	1934	+ 3.09
LC-S75	1874	- 0.10
NC-S75	1866	- 0.53
SC13-H75	1861	- 0.80
PSB3	1787	- 4.74
Syn. 7602	1759	- 6.23
Mc-C_0	1758	- 6.28
ICI 266	1505	-19.77
NHB 3	1390	-25.90
ICI 7540	1111	-40.70
Syn. 7603	1087	-42.05
Mean (30 locations)	1876	

Distribution of Seed Material

During 1976-1977,5 153 seed lots of germplasm -breeding and source material consisting of inbreds, restorers, hybrids, synthetics, populations, population progenies, and experimental varieties-were distributed to breeders in 18 countries.

Information Dissemination

ICRISAT's Cereal Improvement program publishes and distributes *Semi-Arid Cereals,* a newsletter devoted to topical research results with contributions from ICRISAT and cooperators. *Semi-Arid Cereals* is published in French and in English, and is intended to be a worldwide forum for all cereals scientists. Apart from this the Pearl Millet Improvement program publishes both formal and informal research reports. The library is preparing to publish a bibliography of *Pennisetum americanum* literature.

Physiology

Development and Anatomy

Projects on the growth and development of the pearl millet plant, on the anatomy of pearl millet, and on the morphological and anatomical description of the development of the millet panicle have been completed. Illustrated reports of the first two projects are being prepared and the results of the third will be published in the proceedings of the First Annual Symposium on the Physiology of Sexual Reproduction in Flowering Plants, held at Ludhiana in 1976.

The report on millet growth and development includes sections on seed morphology, growth stages, and growth patterns of the leaf, stem, root, panicle, and grain. The life cycle of the millet plant consists of nine easily identified stages of development, as listed in Table 19. Time required for the plant to complete the stages may vary with cultivar; in Table 19 the Indian hybrid HB 3 is compared with the West African landrace cultivar Mel Zengo.

The report on pearl millet anatomy includes illustrations and detailed descriptions of the leaf, stem, root, panicle and grain anatomy in a number of genotypes. Leaf cross-sections (Fig 22) show the characteristic Krantz tissue associated with the C4 photosynthetic system. Vascular bundles are surrounded by large sheath cells which contain a high concentration of chloroplasts (dark staining material arranged in semilunar pattern towards the periphery of the

Table 19. Growth stages in the pearl millet plant.

Growth stage	Major growth period	Identifying characteristic	Approximate time after emergence	
			HB 3	Mel Zengo
			(days)	(days)
0	GS_1	Emergence. Coleoptile visible at soil surface	0	0
1	"	Collar of third leaf visible	6	6
2	"	Collar of fifth leaf visible	14	15
3	GS_2	Growing point differentiation	22	28
4		Final leaf visible		43
5	"	Boot stage. Head extended into flag leaf sheath	35	47
6	GS_3	Half bloom	40	53
7	"	Soft dough	54	63
8		Hard dough	58	69
9		Physiological maturity	65	75

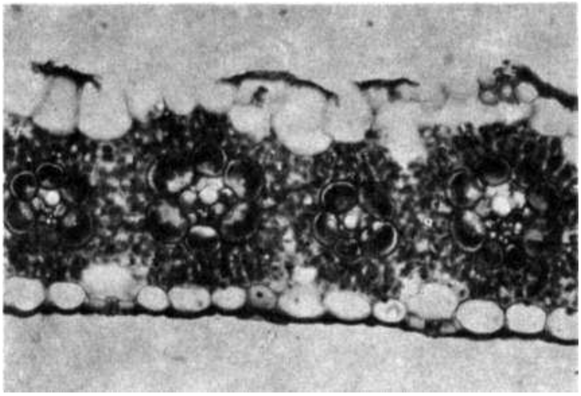


Figure 22. Transverse section of the leaf lamina of pearl millet hybrid HB 3 showing the characteristic bundle sheath cells of the C4 plant.

cells). Surrounding these are the smaller mesophyll cells, also containing chloroplasts. Marked cultivar differences in the concentration of chloroplasts in the bundle sheath cells were noted.

Effects of Drought-screening Treatments on Crop Growth and Yield

In order to learn more about the effects of artificial stress treatments used in screening for drought resistance, detailed measurements of crop growth and yield were carried out on irrigated and on stress treatments during the hot dry season. The stress treatments used were a mid-season stress (from 30 to 64 days after emergence) and a terminal stress beginning at flowering (48 days after emergence).

Crop duration was shortened by 10 days and the total crop growth reduced by about 30 percent in the terminal stress treatment (Fig 23). The mid-season stress caused a marked reduction in crop growth during the treatment period, as well as an apparent depressive effect on growth rate following termination of stress. Total dry weight and maximum leaf area index achieved in this treatment were only approximately 60 percent of those in the control, and crop maturity was delayed more than 20 days.

Grain yields, similar in both stress treatments, were approximately 45 percent of those in the control (Table 20). The way in which yield reduction occurred, however, differed between the two stress treatments as different yield components were affected by the different timing of the two treatments.

Yield reduction in the terminal stress treatment occurred because of the failure of the late tillers to develop (compare the differences in panicle numbers between this treatment and the control at 64 days and at maturity, Table 20) and because of a reduction in size of the grains filled under stress. Yield reduction in the mid-season stress treatment was due entirely to a reduction in the productivity of the average panicle. Tillers whose development was interrupted during the stress resumed growth after the stress was terminated (again compare panicle numbers at 64 days

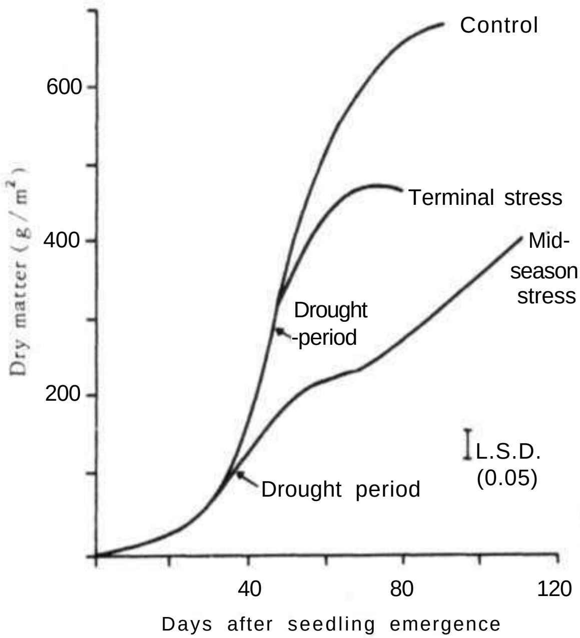


Figure 23. Effects of stress treatment on crop dry-matter accumulation. Arrows indicate time of application of drought stress. The mid-season treatment was relieved on Day 65; the terminal stress treatment was not relieved, as the crop had senesced by Day 80.

Table 20. Effects of drought-screening stress on yield and yield components.

Treatment	Grain yield	Maximum leaf area index	Panicle number: At 64 days after emergence	Panicle number: At harvest	Seeds per panicle	100-seed weight
	(kg/ha)		(no/m^2)	(no/m^2)	(no)	(g)
Control	2115	3.20	25	41	865	0.64
Mid-season drought	1 196	2.00	14	44	589	0.48
Terminal drought	1097	2.60	24	24	989	0.49
L.S.D. (0.05)	176	0.7	2	5	106	0.04

and at maturity), but the grains produced per panicle were significantly smaller and fewer in number.

The data suggest that resistance to a mid-season stress might be related to ability to promptly resume growth and produce near-normal panicles after termination of stress. Resistance to terminal stress, on the other hand, might be improved by synchronization of tiller development and by maximum use of resources for grain-filling under stress conditions.

Screening Breeding Material for Drought Resistance

A two-stage screen is used to measure, in terms of yield reduction, the response to drought stress in material drawn from germplasm and the breeding program.

The first stage consists of a nonstress control compared to a single 30-day stress applied at panicle initiation (about 21 days after planting). These are applied in different parts of the field without replications, though there are regular plots of check varieties. The second stage is a replicated experiment with four treatments - two as above, one with a terminal stress from flowering onwards, and one with a short stress at panicle initiation followed by terminal stress from flowering.

The 1976 drought work involved the initial stage only. Avoidant types, which produced grain yields of 1 500 to 2 000 kg/ha in stress (from one-half to three-fourths that of their counterparts in control), were identified. Tolerant entries, mainly by means of poststress recovery (tiller production), gave yields equivalent to nonstress yields (2000 to 2500 kg/ha).

In 1977, the period allowed for poststress recovery was reduced, which reduced yields, so that both the best tolerant and avoidant types produced 1 000 to 1 500 kg/ha under stress, which was 50 to 60 percent of the yields when grown without stress.

The advanced screen introduced in 1977 showed that the terminal stress applied at flowering (47 days after planting) was critical in terms of grain production. Most entries produced only 600 to 900 kg/ha in the two treatments involving this stress, 20 to 40 percent of that of nonstressed controls.

Initially, within the drought-resistance project, crosses are being made between resistant lines and also between breeders' advanced progenies from other projects. The first set of crosses were screened as F_2 populations in the 1977 nursery and single-plant selections were made in the stress treatment. A group of lines, some of which were selected in 1976 and again in 1977, will be evaluated in rainy season 1978 for possible incorporation into either avoidant or tolerant composite populations.

Relationship Among Plant Type, Population, and Planting Pattern

Farmers' cultivars and landraces of millet include a wide variety of plant types and are grown in a wide range of planting geometries and plant populations. We have initiated studies to determine if there are interactions among plant type and planting system; if so, they might be important in variety selection and testing. In one such study three cultivars, of contrasting height and tillering habit, were grown at a range of plant populations from 3 to 25 plants per square meter in wide rows, narrow rows, and with all plants equally spaced.

Population seemed to have no effect on grain yields, as all genotypes demonstrated a remarkable ability to adjust to changing crop competition. Individual plant yields increased sixfold as population declined from 25 plants/m^2 to 3 plants/m^2. The yield per plant was unaffected by planting pattern at high populations, but was less in the equidistant planting at the low populations. These results suggest that population *per se,* over a broad range, is not a determinant of millet yields, at least where fertility is adequate.

Planting pattern, in contrast, had a highly significant effect on yield, which was independent of both genotype and of plant population. Grain yields were significantly different in the order of wide rows > narrow rows > equidistant planting (Fig 24). The yield differences were due to increases in dry weight of individual tillers, and to leaf area, grain number, and grain yield (tiller numbers per unit area were constant), emphasizing the role of tiller productivity in maximizing yield.

These studies are now being expanded to include hill-planting systems, various fertility levels, and a wider range of cultivars.

Millet Genotype Evaluation

Analysis was completed on the large-scale experiment of 1976 in which relationships between yield, yield components, and length of the major growth stages were evaluated. Results were analyzed separately for the entire set of 50 genotypes, as well as for smaller subsets representing the high-tillering Indian hybrid type and the lower-tillering West African type. Differences in grain yield between the two subgroups were not statistically significant, but there were significant differences in tiller number per plant, seed number per plant, and harvest index (Indian types were superior); and in grain number per panicle and length of the GS_2 stage (West African types were superior).

The relative contributions of different yield components in each group were assessed in a multiple linear regression model of yield on panicle number per plant, grain number per panicle, and grain size (100-seed weight). Over the entire set, seed number and grain size accounted fdr 45 and 42 percent, respectively, of the variation in yield, with panicle number account-

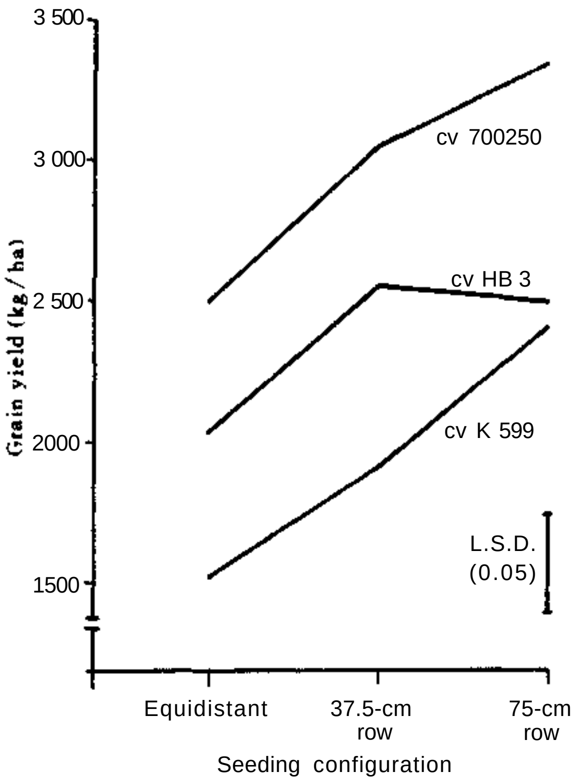


Figure 24. Grain yield of three pearl millet cultivars as affected by geometry of planting. Mean data from a series of five planting populations ranging from 3 to 25 plants/m^2.

ing for only 9 percent (Table 21). In the high-tillering group seed number per panicle was the predominant variable determining yield, accounting for nearly 70 percent of the observed yield differences. The magnitude of this term indicates that selection for panicle size within the high-tillering types should be effective in increasing yields. In the low-tillering group, the number of panicles per plant was the predominant variable, but there were also significant contributions from seed number per panicle and seed weight. Thus yield increases in these types should be possible by improvements in both panicle number and panicle productivity.

The analysis of the relationship of yield to the lengths of the various growth stages confirmed the hypothesis that an increase in the length of the GS_2 stage (panicle initiation to flowering) up to an optimum of 25 to 30 days resulted in maximum yields. The length of the grain-filling phase, in contrast, varied only slightly among the genotypes and was not strongly related to yield differences. •

Entomology

At ICRISAT Center in 1976-1977, pest damage to pearl millet was minimal. Detailed observations were carried out on blocks of the crop sown in nonsprayed areas; although 63 pest species were recorded, none were damaging. The potentially important pests, *Atherigona approximata, Chilo partellus,* and *Calocoris angustatus* were at low levels.

The root aphid, *Rhopalosiphum rufiabdominalis* Fitch, caused some wilting in breeders' plots sown on Alfisols. The ant, *Monomorium indicum* Forel, removed seed from plot rows and piled it near nests, causing low plant populations on breeders' and agronomy plots as well.

A list of insects found on pearl millet was prepared for publication.

Pathology

The fungal diseases-downy mildew (caused by *Sclerospora graminicola),* ergot (caused by *Claviceps fusiformis),* and smut (caused by *Tolyposporium penicillariae*) -cause severe damage and yield reduction in many of the new high-yield-potential pearl millet cultivars and hybrids. Activities in ICRISAT's pearl millet pathology program are directed to the control of these diseases through the identification and utilization of stable host-plant resistance. During 1976, screening techniques were evaluated and significant progress has been made in finding and using resistance to downy mildew.

Downy Mildew

The traditional screening method of planting test

Table 21. Relative contribution of yield components (all variables in logarithmic form) from the model $Y=b_1x_1 + b_2x_2 + b_3x_3$.

Variable	Fraction of the total sum of squares (R^2)		
	All genotypes[a]	Low-tillering subset[b]	High-tillering subset[b]
Panicle/plant	0.089	0.395	0.118
Seeds/panicle	0.448	0.247	0.688
100-seed weight	0.417	0.202	0.176

[a]Total of 50 in the complete set.
[b]Total of 17 in sublet.

materials in a sick-plot (i.e. a field in which the soil contains resting spores of the DM causal fungus) is unreliable and restrictive. A new technique was required which (i) would allow even exposure to inoculation of many thousands of segregating lines, (ii) would allow flexibility in size and location of the testing site, and (iii) could be used efficiently in the postrainy season as well as in the rainy season. Evidence from two field experiments during the rainy season clearly indicated that the sporangia (ephemeral asexual spores produced in millions on infected plants each night) played a major role in the early infection of plants and buildup of the disease (development of the epidemic) in the field when high humidities prevailed. This information was used to develop a screening technique based on sporangia produced by "infector rows" (a known high-susceptible hybrid) planted in every third row 15 days before seeding of the test rows. Inoculum is provided for initiating infection in the infector rows by strategically placed pots of infected plants, and the necessary humidity is provided by fine-mist irrigation in the evening hours. The test materials are planted when the infector rows show rapid disease development (15 to 21 days after seeding of the infector rows) and the mist irrigation is continued twice weekly until the test materials reach heading stage. Throughout the screening area, after every 10 test lines, a known high-susceptible hybrid (indicator) is planted at the same time as the test lines in order to measure the success of the inoculation process. This technique was highly effective during both the rainy and postrainy seasons in 1976, and details of the screening results are presented below and in the breeding subprogram report.

Screening Activities at ICRISAT Center

Using the infector-row system, 4 hectares of breeding material were screened at ICRISAT Center for resistance to DM in both the rainy and postrainy seasons. This was a joint activity between the breeding and pathology staffs. In the population-improvement materials, selfing and sibbing for the next cycle of selection was carried out in the disease nursery utilizing only DM-resistant plants. A measure of the advance achieved in this process is presented in Table 22.

In addition to the ICRISAT breeding materials, 230 millet lines were tested in the disease nursery for scientists working in the All-India Coordinated Millet Improvement Project.

Multilocational Screening

The International Pearl Millet Downy Mildew Nursery (IPMDMN). One of the features of certain types of resistance is that it "breaks down" through the ability of the pathogen to overcome the resistance. In an attempt to find

Table 22. Comparison of downy mildew susceptibility in four populations after one generation of selection under heavy disease pressure during rainy and postrainy seasons at ICRISAT Center, 1976.

Population	Lines with < 5 % incidence		Maximum incidence	
	Rainy[a]	Postrainy	Rainy	Postrainy
	(%)	(%)	(%)	(%)
GAM 73 S_2's	3.1	50.0	76.59	50.0
GAM 73 FS	. 9.0	16.7	69.35	41.4
GAM 75 S_1's	0.0	9.5	87.75	69.7
Late Composite	33.3	68.4	59.57	31.0

[a]Resistant plants were selfed in rainy season 1976 and the progeny retested during the postrainy season.

stable resistance, a multilocational testing program was initiated in 1976 in which millet lines resistant at ICRISAT Center were exposed to many populations of the downy mildew pathogen. The 1976 IPMDMN, the first disease nursery in the International Pearl Millet Disease Resistance Testing Program (IPMDRTP), contained 46 entries and was tested by cooperators at 24 locations in five countries in Asia and West Africa. Ten entries, all of which originated in West Africa, showed an excellent level of across-location resistance. This is encouraging, for while many other cultivars were resistant at Indian locations they were highly susceptible at some of the West African locations (Table 23). It is not clear whether these differences in reaction are due to different pathotypes, different environments, or both-but it is clear that some millet lines have more stable resistance than others, and that the West African locations are essential to our program for the identification of stable downy mildew resistance.

Seed-transmission Investigations

The activities of the ICRISAT Millet Improvement program require movement of millet seed across national boundaries and between continents. This movement must not facilitate movement of pathogens. In view of recent reports of possible seed transmission of the downy mildew organism, we continued an intensive investigation of possible seed transmission of pearl millet DM during 1976. Oospores of the causal fungus were found to adhere to external surfaces of pearl millet seed, but in this position they are vulnerable to simple seed-treatment procedures. In order to demonstrate internal seed transmission of the disease, infected plants must be produced from suspect seed in an environment free from all external inoculum sources and conducive for symptom development. During 1976, we grew-on sterilized agar medium in large sterile boiling tubes-985 plants from surface-sterilized seed harvested from infected heads, and no downy mildew symptoms were detected. Young seedlings growing in this way and inoculated with sporangia developed symptoms in 6 days, indicating that the environment was conducive for symptom development. In several such studies to date we have obtained no evidence of internal seed transmission of pearl millet downy mildew from thoroughly dried mature seed that was surface-sterilized prior to planting in inoculum-free environments. We are continuing to look at the effects of drying and various other seed treatments on possible seed transmission.

Table 23. Comparison of downy mildew incidence in five peal millet cultivar African locations.

Entry	India		West Africa	
	Hissar	ICRISAT Center[a]	Samara	Ouahigouaya
	(%)	(%)	(%)	(%)
Syn 7601	0.7	1.2	68	18
ICH 105	0.2	1.5	84	15
Ex-Bornu	0.0	2.2	18	2
WC-C75	0.6	1.7	17	1
PHB 14	0.0	14.5	4	14

[a]In the DM scneening nursery.

Ergot

Less progress has been made with ergot than with downy mildew. During 1976, intensive studies were made on factors influencing infection, and the information from these studies was used to develop an effective screening technique. A limited amount of screening for resistance was carried out and the validity of the results will be rechecked during 1977.

Factors Influencing Infection

Inoculation of heads when the female parts of the flowers are most receptive (protogyny stage) produces maximum infection. Freshly produced spores from the "honey-dew" of infected plants are more infective than spores of dried "honey-dew" and both produce more infection than spores contained in dried resting bodies (sclerotia). Experiments were conducted with different inoculum concentrations, different methods of inoculum application, and use of selfing bags to enclose the head after treatment. The greatest infection takes place when heads are inoculated by dipping during the protogyny stage with spores from fresh honey-dew at a concentration of 100 x 10^3, and when heads are bagged immediately after inoculation. Inoculation in the late evening hours is also beneficial for increased infection.

Effects of Pollination and the Path of Infection

Heads inoculated after pollen shedding are less susceptible than heads inoculated before this event. This led to the hypothesis that pollination and fertilization inhibited infection. We inoculated with male-sterile lines (i.e. lines which produce no viable pollen) at different stages in the flowering process and found that the rapid fall in susceptibility occurred in the same way as with male-fertile heads, with the withering of the stigmas (female parts of the flower). This indicates that the infection path is likely to be through the stigmas. Some evidence to confirm this has been obtained from microscopic examination of florets at varying times following inoculation, and further experiments are planned with controlled pollination and inoculation of male-sterile heads.

Resistance Screening

About 4000 breeding lines were dip-inoculated (without bagging) during August 1976. Eighty-two lines developed no ergot; these will need to be thoroughly rechecked during 1977, using the procedures for optimum inoculation described above. A total of 488 millet lines selected in preliminary screening in 1975 were retested during 1976 by the dipping and bagging technique. Twenty-two lines developed only slight infection, and these will be tested at several locations in 1977.

Smut

Examination of Screening Techniques

It has been considerably more difficult to find an effective technique for screening pearl millet lines for smut resistance at ICRISAT Center than it was for downy mildew and ergot.

During the hot dry summer season of 1976, a reasonably high level of infection was obtained by injecting a suspension of smut spore-balls into the top of the boot (immediately prior to head emergence). However this method did not produce good infection at ICRISAT Center during the rainy season. Intensive study is continuing on factors possibly affecting infection. Until a reliable inoculation technique is developed, little progress can be made in resistance identifications at ICRISAT Center.

Rust

Rust, caused by the fungus *Puccinia penniseti,* is a leaf disease with great destructive potential. All improved millets should carry a sufficient level of stable resistance to this disease if they are to be utilized successfully over a long period. During rainy season 1976, 193 lines selected in earlier screening at ICRISAT were tested at Bhavanisagar in Southern India where rust normally occurs in severe form on susceptible millet. Under these conditions, 10 of the entries developed no rust and 64 entries showed less than 5 percent disease based on a standard (Cobb's Modified) rating scale.

During postrainy season 1976-1977, the disease appeared in severe form in germplasm material at ICRISAT Center. A total of 128 single-plant selections were made. These selections and those found free of rust at Bhavanisagar will be tested in 1977, in a Preliminary Pearl Millet Rust Nursery (PPMRN), at several locations where the disease is known to occur.

Nutritional Quality

Standardization of Laboratory Methods

The Technicon Auto Analyzer was found to be the easiest of several methods of protein estimation tried and gave the best relationship (r = 0.99) with micro-Kjeldahl values over a wide range of protein levels. During the year 4 600 samples were analyzed for protein content; they ranged from 5.8 to 20.9 percent, with a mean value of 10.6 percent.

For lysine estimation, samples were weighed to contain constant amount of protein (80 mg) and analyzed by DBC (dye-binding capacity) method. A good correlation was obtained (r = 0.92) between DBC values and actual lysine concentration. Investigations are in progress to relate the DBC values obtained on constant weight of sample and protein values with lysine concentration in the sample. Lysine content was estimated in 1400 samples by the DBC method during the year.

Analysis of Breeding Material

Initial analyses for protein content indicated that there was a problem of variability within each genotype, with coefficients of variation ranging from 12 to 23 percent, and that environment greatly affected protein level. We therefore selected a number of high- and low-protein lines and planted a replicated trial in three different environments in 1976, in order to determine the stability of protein content. Results indicate protein content was higher under conditions of lower productivity. Environment seems to play a major role in influencing protein content. Among locations, protein content was highest at Hissar and lowest at Bhavanisagar. This may relate to differences in grain-filling periods.

Progenies in several composites showed a wide range in protein content from 8 to 15 percent (in one case 19%), indicating possibilities for improvement by selection. From analyses on the same cultivar at different yield levels, the relationship between yield and protein content was not as strongly negative as expected. Content of 11 percent protein at yields of 3000 kg/ha would seem feasible. Using the working collection, a slight negative correlation (r = 0.23**) was found between oil and protein content, but no relationship was indicated between 100-seed weight (0.24 to 1.4 g) and protein content (6.0 to 14.5%).

Microbiology

One hundred and sixteen lines and landrace cultivars of pearl millet were grown on Alfisol at ICRISAT Center under low-fertility conditions (only 9 kg P/ha fertilizer added) over three seasons - rainy, postrainy, and hot dry summer-to see if differences between lines in ability to stimulate nitrogen fixation by bacteria in the soil could be detected. Nitrogen-fixing activity was estimated by an acetylene-reduction assay using cored soil samples containing plant roots, as was the procedure for sorghum (page 43). Preliminary findings indicate that the single core probably represents about one-eighth to one-half of the total activity for plants, dependent on the growth stage.

About 50 lines had some nitrogenase activity greater than 50 μ g N/core per day, and 12 had more than 100 μ g N. There were significant differences between lines despite the large plant-to-plant variability. The reason for this variability is yet not clear. Most activity was found after flowering, and continued well into the grain-filling stage. Activities during the cooler postrainy season were lower than in the rainy season until the temperatures increased in March. Four lines had consistently high activity in more than one season. Little activity occurred in the summer planting.

Using a 3:1 ratio to convert ethylene production into amount of nitrogen fixed, the highest activity was obtained with the line IP 2787 with a mean fixation for five plants of 560 μ g N/core per day, with a standard deviation of 749, and a range of activity from 17 to 1 586 μ g N/core per day. Other lines assayed at the same time had activities similar to that of soil cores without plant roots-6 μ g N/core per day. The activity on a dry-root-weight basis for IP 2787 was also high (2.29 μ moles C_2H_2g per hour), though the large support roots near the crown dominate the root weight of our cores.

Fixation associated with the GAM-73 population assayed throughout the grain-filling stage varied from 16 to 80 μ g N/core per day (mean of five plants). For the growth stage at which nitrogen fixation is most active, individual plants ranged from 23 to 183 μ g N/core per day. Nitrogenase activity of GAM-73 throughout the summer season was positively correlated (r = 0.7) with soil moisture content in the top 20 cm of an Alfisol (Fig 25).

The minor millets - *Eleusine coracana, Panicum* spp, *P. miliare, P. miliaceum, Paspalum scrobiculatum, Eragrostis tef, Echinocloa colonum* and *Setaria italica*-also had nitrogenase activity, as did some grasses (Table 24).

Intercropping

In four previous experiments with millet and pigeonpea at ICRISAT Center, the intercropping advantage averaged 22 percent. In this combination, the large difference in crop maturities played a major part in the positive interaction between the two crops.

Where there is little or no temporal difference in growth patterns, intercropping may still be advantageous due to better "spatial" use of resources. This aspect was probably important in a 1976 experiment, in which four genotypes of pearl millet in all combinations with four genotypes of sorghum were examined. Nine of the 16 combinations gave advantages greater than 10 percent. The two highest advantages-in excess of 30 percent -came from the combinations of latest sorghum with earliest millet (sorghum 21 days later at harvest) and earliest sorghum with latest millet (millet 14 days later). The combination with the largest difference in height (sorghum 104 cm taller, and also 9 days later) gave an advantage of 24 percent.

Next year, pearl millet will be grown in combination with groundnut in order to study growth patterns, plant population/spacing, genotype, N- and P-response curves, N fixation, and weed competition.

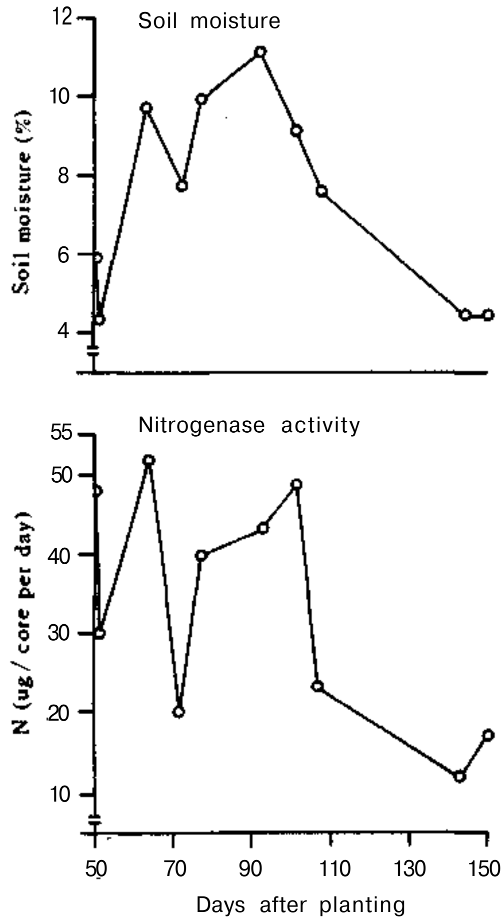


Figure 25. Relationship between soil moisture content in the root zone and nitrogenase activity of pearl millet GA M 73 grown in Alfisol at ICRISAT Center, hot dry season 1977.

Table 24. Tropical grasses and minor millets with high nitrogenase activity.

	Nitrogenase activity
	(µg N/plant per day)
Napier bajra (*Pennisetum purpureum* x *Pennisetum americanum*)	1788[a]
Setaria sphacelata	1353[a]
Pusa giant napier *(P. purpureum)*	780'
Pennisetum orientate	369[a]
Panicum antidotale	261[a]
Panicum maximum	196[b]
Panicum miliare	51[b]
Eleusine coracana Sharda	176[b]
Setaria italica ISE186A	376[b]
S. italica Arjuna	343[b]
Sorghum halepense	322[b]
Chloris gayana	85[c]
Cymbopogon citratus	117[c]
Echinocioa colonum	15[c]
Pennisetum oleopecuroides	267[c]

[a]Total for three cores containing roots of one plant.
[b]Mean of single cores from five plants.
[c]Mean of single cores from three plants.

Looking Ahead in Pearl Millet Improvement

Germplasm. In collaboration with IBPGR, further collections of germplasm are planned in priority areas of West Africa and in Rajasthan in India.

Breeding. The breeding program will continue to produce new varieties, synthetics, and hybrid parents for national and international testing, together with nurseries and resistance sources for breeders in national and regional programs.

The breeding program provides for the introgression of desirable material-such as new sources of disease resistance - into existing composites; these are routinely used in variety crosses.

New seed parents, particularly if they involve the A_2 and A_3 types, are now an urgent requirement. An increased number of crosses have already been made and additionally the IB and IR composite pair, designed to produce both seed and pollen parents, will come on stream in 1977.

To further ICRISAT's role of fostering cooperation and interchange between millet scientists around the world, an International Workshop on Pearl Millet is scheduled to be held at ICRISAT in September of 1977.

Physiology. We plan to evaluate seasonal effects on the development, growth, and yield of a standard set of millet cultivars in order to assess how such cultivar performance is influenced by season, and how much importance should be placed on off-season yield testing and physiological studies.

We are planning experiments to help us determine how far we can extrapolate the results of our off-season drought-resistance screening. This will include testing the effects of a range of different stress treatments within the dry season and the establishment of a small nursery to be grown in drought-prone areas during the rainy season.

Work on seedling vigor in millet will be expanded. Experiments will include comparison of methods for evaluating seedling-growth rates under favorable conditions, and development of methods for screening seedlings for drought tolerance and ability to emerge from crusted soils.

Entomology. Observation on pest levels in standard cultivars will continue. Material coming forward from the breeding program will be assessed for relative susceptibility to pests, using standard cultivars as checks. Most of the entomological work on pearl millet will be done in West Africa where pests are more of a problem. Any millet pest species that becomes a problem anywhere in the SAT will be investigated.

Pathology. The large-scale field screening for downy mildew resistance at ICRISAT Center and the multilocational screening in Africa will continue with an expansion of the latter. In this way, sources of location-nonspecific resistance will continue to be identified and incorporated into the elite materials in the program. The efficacy of seed treatment with Ridomil will be evaluated on a multilocational basis.

By appropriate breeding procedures, lines low in susceptibility to ergot will be used to develop higher levels of resistance. The possibility of control through pollen management will be investigated.

Initial screening for smut resistance will continue at Hissar and advanced screening will be made at several locations in West Africa and at Hissar. Smut resistance will be incorporated into the breeding materials by appropriate breeding methods.

With rust, investigations on variability in causal species are required. The resistance-screening work will continue with initial screening at ICRISAT Center and Bhavanisagar and advanced screening at several locations in India.

The levels of susceptibility to blast in our elite materials will be investigated at known hot-spots. If necessary a screening program will be organized to identify resistance and to incorporate the resistance into breeding materials.

Nutritional quality. Standardization of methods for protein estimation will make it possible to handle a larger volume of materials for the breeding program. More work will be focused on other important areas, such as cooking quality and digestibility.

Microbiology. In this program, the aim is to determine if nitrogen-fixing bacteria closely associated with roots of pearl millet have the potential for reducing the amount of nitrogen fertilizer required by the crop. Techniques for measuring the amount of nitrogen fixation associated with pearl millet cultivars will be refined, and lines with enhanced nitrogen-fixing capability will be sought.

THE PULSES

Pigeonpea (*Cajanus cajan*)

Chickpea (*Cicer arietinum*)

Grain legumes are expected to play increasing roles in providing adequate protein in the diets of the underfed of the SAT. Chickpea, third-ranking of the world's pulses, is now planted on some 10.5 million hectares throughout 10 nations in the SAT. Pigeonpea plantings approach 3 million hectares. Both crops are utilized as human food, and are of vital importance to millions of persons in areas where crop production is erratic or otherwise limited. Both have high contents of protein - 18 to 24 percent and more-and contain some amino acids not found in cereals. When combined with rice, sorghum, millet, or wheat, chickpea and pigeonpea provide an adequate balanced protein-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 crop species and will be able to make rapid headway. 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 gennplasm 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 on the highway between Hyderabad and Bombay, the facility includes two major soil types found in the semi-arid tropics. The red soil (Alfisol) is light and droughty; the black soils (Vertisols) 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, postrainy, 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 postrainy season of October through January, also known as postmonsoon 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 postrainy 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

Pigeonpea

Previous reports have highlighted the. broad objectives of the pigeonpea improvement program, and have listed our observations on the effects of photoperiod response, rainfall distribution, and climatic variations, all of which contribute to strong local adaptation of cultivars. At ICRISAT Center, we are continuing our emphasis on studies of physiology of the plant, the biology of insect pests and diseases and the plant's reactions to these, and development of pools of genetic diversity, all of which have not only local but broad application.

Our selection for high-yielding locally adapted types at ICRISAT Center and the cropping systems under study may have limited application elsewhere, but are important to the region represented by this location. In 1976 we added a location where early maturity types are adapted and another location where very late types are best. We are emphasizing the development of breeding populations for use by breeders in those regions of adaptation.

In the following paragraphs we have summarized what we consider to be the important developments during the year; where appropriate we have presented the results accumulated to date.

Germplasm Collection and Evaluation

Germplasm resources were increased by 263 accessions collected from five states in India. We are extremely short of germplasm from Africa (Table 25), and 120 samples collected in eastern Kenya are still to be cleared by Plant Quarantine officials.

Efforts to further describe the germplasm during the year were disappointing. Heavy August rains on a poorly drained field contributed to unsatisfactory survival and growth of 2981 accessions planted for recording their morpho-agronomic traits. A set of 1000 lines were planted at Kanpur, U.P.; Kathalagere, Karnataka; and ICRISAT Center for determining environmental effects on growth and protein content. With generally unfavorable weather, only 280 accessions produced seed at all three locations. These samples have been sent to the Canadian Grain Commission, Manitoba, for rapid protein determination.

A 4-year experiment is in progress to compare perennial growth habit, yield, and regrowth potential of 45 accessions (5 early, 20 medium, and 20 late). Three of the six replicates were ratooned. Observations of the first year's planting indicate that early types behave as annuals.

Table 25. Countries of origin of pigeonpea germplasm at ICRISAT Center.

Country	Entries
Australia	14
Bangladesh	18
Brazil	6
Burma	27
Colombia	5
Dominican Republic	6
Ghana	1
Guyana	4
India	4795
Indonesia	1
Jamaica	13
Madagascar	1
Mexico	2
Nepal	3
Nigeria	19
Pakistan	4
Peru	5
Puerto Rico	40
Senegal	10
Sri Lanka	55
Thailand	2
Trinidad	38
USA	2
Unknown	360
Total	5431

Available data on germplasm accessions are being computerized and a catalog is expected to be issued in 1978. Even without a catalog, we have strong demand for material (Table 26).

Elite Lines from the Germplasm

Lines from plants selected from the germplasm for agronomic.value were tested in intercropping and sole cropping at ICRISAT Center and at three locations in sole cropping by APAU. In sole cropping, the check cultivars were highest in yield, while in intercropping the checks were generally low and some of the new selections were high. The highest-yielding selections will be retested, and seed is being increased for international testing. Pigeonpeas of medium maturity are usually grown in inter- or mixed-cropping, while breeding material is normally selected while growing as a sole crop and evaluated as a sole crop. In view of this year's results, which are supported by some earlier studies, we are expanding not only testing but also selection in segregating material grown as an intercrop.

Evaluation of Hybrid Populations

Evaluation of germplasm lines as parents for hybrids has been a major effort in the breeding program. Once a number of crosses have been made, it is important to determine which hybrids are worth advancing for selection. We experimented with testing of F_1, F_2, and F_3 generations from three crosses. The results indicated that a yield test of F_2's would discriminate among crosses for additive genetic factors for yield. We also compared parents and F_2's of 21 crosses. In this test, the correlation between F_2 and mid-parent yields was only 0.47, indicating that actual F_2 yields could not be accurately predicted on the basis of performance of parents.

Characters with high heritability can safely be predicted by parental performance. The correlations between F_2 and mid-parent values for seeds per pod was +0.90 and for seed size was +0.80. We have concluded that routine testing of F_2 populations in replicated tests will increase the efficiency of breeding for yield by allowing the discarding of all but the best populations.

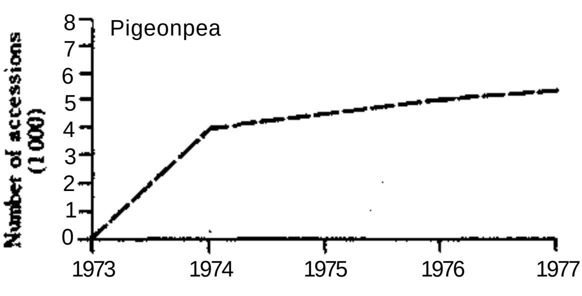


Figure 26. Pigeonpea germplasm accessions at ICRISAT Center.

Progress with Early Maturing Selections

Our most advanced lines from the breeding program are in F_6 generation, and these are early lines of which two generations per year could be grown. Replicated yield tests in the coming year will provide our first valid assessment of yield gains. In early cultivars, generally small seed size causes a market disadvantage. Table 27 shows the increase in seed size achieved in selections comparable in maturity with three early cultivars. We are currently selecting for an intermediate seed size of 10 to 12 g/100 seeds and are continuing to investigate the relationship of seed size with grain yield.

Genetic Male Sterility

Observations during the year verified that the ms_1 gene is a simple recessive which confers complete pollen abortion in the homozygous recessive. Pollen-sterile plants are easily identified by the whitish translucent appearance of the anthers. We were interested in the usefulness of

Table 26. **Pigeonpea germplasm lines supplied to research agencies in India and other nations dining 1976-1977.**

Institution	Location	Entries
INDIA:		
Millet Research Station of Lam	Guntur, A.P.	36
Millet Research Station	Madhira, A.P.	36
Kakatiya University	Warangal, A.P.	26
Indian Lac Research Institute	Namkum, Ranchi, Bihar	21
Agricultural Research Station of Maktampur	Broach, Gujarat	100
University of Agricultural Sciences	Bangalore, Karnataka	1000
College of Agriculture	Dharwar, Karnataka	60
Medium Research Station	Gulbarga, Karnataka	78
J.N. Krishi Vishwa Vidyalaya	Jabalpur, M.P.	57
Mahatma Phule Krishi Vidyapeeth	Rahuri, Maharashtra	1
Punjab Agricultural University	Ludhiana, Punjab	11
Rajasthan College of Agriculture	Udaipur, Rajasthan	300
K.K. Agricultural Experimental Station	Kudumaimalai, Tamil Nadu	1
College of Agriculture	Madurai, Tamil Nadu	2
Crop Introduction & Diversification Station	Ootacamund, Tamil Nadu	9
Central Soil & Water Conservation Research & Training Institute	Dehra Dun, UP.	15
Indian Grassland & Fodder Research Institute	Jhansi, U.P.	1100
Chandra Shekhar Azad University of Agriculture & Technology	Kanpur, U.P.	1028
B.C. Krishi Viswa Vidyalaya	Kalyani, W. Bengal	1
OTHER NATIONS:		
Department of Agriculture	Perth, Australia	1000
Institute of Nuclear Agriculture	Mymensingh, Bangladesh	15
Secretaria de Estado de Agricultura	San Cristobal, Dominican Republic	310
Crops Research Institute	Bunso, Ghana	50
Hebrew University of Jerusalem	Rehovot, Israel	103
Tropical Agricultural Research Centre	Ibaraki-ken, Japan	6
Minor Irrigation Projects, FAO	Nakuru, Kenya	25
Institute of Agricultural Sciences	Suweon, Korea	20
Department of Agriculture	Kuala Lumpur, Malaysia	25
Section Cultures Maraicheres, Centre National de Recherches Agronomiques	Kaedi, Mauritania	51

continued

Table 26 *continued*

Institution	Location	Entries
Department of Agriculture	Lalitpur, Nepal	8
University of Ibadan	Ibadan, Nigeria	84
Ministry of Agriculture & Natural Resources	Jos, Nigeria	13
University of Philippines	Laguna, Philippines	408
University of Puerto Rico	Mayaguez, Puerto Rico	100
Agricultural Research Station	Maha Illuppallama, Sri Lanka	24
Hudeiba Research Station	El-Damer, Sudan	8
Masalato Christian Education Centre	Dodoma, Tanzania	50
Agricultural Research Station, Bangkhen	Bangkok, Thailand	2

Tabk 27. Number of seeds per pod and 100-seed weight of early maturing and check cultivars of pigeonpea.

Checks & Selections	Seeds per pod		100-seed weight	
	Range	Mean	Range	Mean
	(no)	(no)	(g)	(g)
PANT, A-3 (1)		3.4		8.7
Selections	3.5-4.2	4.0	9.0-15.6	10.1
PRABHAT (2)		3.4		6.3
Selections	3.3-5.1	4.1	-	10.7
UPAS-120 (3)		3.6		7.7
Selections	3.0-5.3	4.1	7.8-15.4	11.1

the male-sterility factor in population breeding, and grew a population involving crosses of the sterile with 14 parent lines. We compared the pod-set on sterile plants (resulting from insect pollination) and found 49 percent of 3 735 tagged buds set pods on male-sterile plants compared with 58 percent of 2120 buds tagged on normal fertile plants in the same population. (These buds were all tagged at the peak of flowering, and the percent pod-set is considerably higher than the observed pod-set over the entire flowering period.)

Under conditions at ICR1SAT Center it appears that pollination of the steriles is sufficient for them to be useful in population breeding. We are expanding our studies of natural crossing on the steriles to determine their possible usefulness in large-scale crossing bf specific genotypes.

Rhizobium Populations in Soil

We are using the soil dilution-plant infection method of counting cowpea-type rhizobia using Siratro (*Macroptilium atropurpureum*) as the test plant. When 160 strains isolated from pigeonpea nodules were tested, most nodulated Siratro - although 14 percent were slow to do so. A small-seeded pigeonpea, cv ICP-7332, also nodulates well in agar deeps and we are now comparing counts using Siratro and pigeonpea as the test plant.

Using Siratro for counting, we found cowpea-type rhizobia varying from less than 100 to more than 10^5/g soil within 0.1 ha during the dry summer. Numbers also varied a hundredfold within the top 30 cm of soil with little apparent relation to soil moisture-one surface-soil sample contained 10^5/g but only 1.3 percent moisture. Numbers increased tenfold after rain in early May. The presence or absence of. a pigeonpea crop in the previous season had little effect on numbers. Such high populations will make it difficult to introduce new strains by seed inoculation.

Rhizobium Strains

From 160 strains of *Rhizobium* isolated from soils in Andhra Pradesh and Maharashtra, 10 highly effective strains in nitrogen fixation were selected for field-inoculation trials in Alfisols and Vertisols. In pot trials with cv ICP-1, these strains produced plants up to 120 percent heavier at 6 weeks than the uninoculated control, which received 240 ppm N in the nutrient solution. The pattern of nodulation showed *Rhizobium* strain effects as well as *strain* x *host* genotype interaction effects. Some of the selected strains form nodules containing a black pigment, and we hope that this will be a useful marker in our inoculation trials. At 60 days after planting only 16 percent of the nodules in Vertisol and 12 percent in Alfisol contained this pigment in uninoculated soils.

Nodulation and Nitrogen Fixation

More than twice as many and much larger nodules were formed during the rainy season in Alfisol than in Vertisol, but after the rains nodule formation in Vertisol was greater, so that by 120 days after planting there were 136 nodules per plant in Alfisol and 200 in Vertisol. However, 96 percent of the nodules in Vertisol and 74 percent of the nodules in Alfisol were hollow, apparently the result of insect attack. The grub damage was apparent from 30 days after planting, and was more severe in the Vertisol plots. Such attack could be a major factor limiting nitrogen fixation by pigeonpea.

During the rainy season, seed inoculation with *Rhizobium* in Vertisol significantly increased the number and dry weight of nodules per plant and plant weight at 45 days after planting, but no effect was found at 80 days or on grain yield.

Where rice had been grown for several years, the soil contained less than 10^3 rhizobia/g soil and in this field pigeonpea responded to inoculation.

Nitrogenase activity per plant increased from 16 μ moles C_2H_4/plant per hour at 30 days after planting in Alfisol to 55 μ moles at 60 days and decreased to 2 μ moles at 125 days. Nodules recovered from Alfisol were more active in nitrogen fixation than those from Vertisol, reflecting differences in the amount of nodule tissue per plant rather than differences in activity per g nodule tissue.

Nodulation of Germplasm Lines

A preliminary survey showed a wide range in nodulation of 731 pigeonpea germplasm lines grown in the field. At 25 days after planting, nodule number per plant varied among cultivars from 5 to 48. By 55 days, the number varied from 10 to 64 per plant. The proportion of apparently active pink nodules and senescent or damaged nodules also varied a great deal and was not apparently related to total number of nodules per plant. For some lines, 40 percent of the nodules were hollow at 55 days.

Screening for Disease and Insect Reaction

Phytophthora Stem Blight

In the unusually wet August of 1976, a stem disease developed which selectively killed cultivars in experimental plots. Identified as *Phytophthora* blight, the disease appears to be caused by a species, not definitively identified as yet, different from *P. drechsleri* var. *cajani* described from New Delhi in 1970. A laboratory-screening technique has been developed; use of a 15- to 20-day-old culture in a 1:200 dilution of inoculum to spray-inoculate 15-day-old seedlings gave the best results. Field observations confirmed by laboratory tests indicate that cv ICP-7065 and NP 69 are good sources of resistance. Screening of parent lines and segregating populations will be a routine part of the resistance-breeding program.

Fusarium Wilt

The development of the two wilt-sick plots, 'A' and 'B', was continued by incorporating stubble of diseased plants and growing susceptible cultivars. The percentage level of "sickness" in plot 'A,' as determined by the wilt incidence in susceptible cv Sharda, was 52.3 and in the newer plot 'B' it was 26.5.

Breeding material was screened in the wilt-sick plot 'A.' Generally high wilt incidence occurred in crosses involving the susceptible parent ICP-6997. Crosses involving NP(WR)-15 performed well. Of the 189 materials tested, 11 F_2, 4 F_3, and one germplasm selection showed less than 25 percent wilt. One F_2 population, ICP-1 x NP(WR)-15, showed only 5.8 percent wilt. Only 7 single-plant progenies out of 318 screened in the sick plot 'B' remained wilt-free. In laboratory screening only 2 single-plant progenies out of 541 screened were unaffected by wilt. None of the 48 materials from intergeneric crosses (*Cajanus* x *Atylosia)* was found promising against wilt in laboratory testing. When "water-culture" wilt screening was done on 1000 individual plants of each of several lines, those with the highest frequency of survival were 15-3-3, BDN-1, No. 148, and ICP-7035.

Sterility Mosaic

We have reported earlier the leaf-stapling technique for infesting test plants with mite vectors of sterility mosaic. We have now completed screening of the existing germplasm, using this technique on young plants. The five resistant lines reported last year - ICP-3783, -6986, -6997, -7035, and -7119-have been confirmed to be resistant, as have four previously unreported lines-ICP-3782, -7687, -7942, and -8113. One line, ICP-2376, shows symptoms which we describe as ring spots, and we are investigating it further. We have identified 29 more lines whose resistance is still to be confirmed in the next generation.

Last year we screened breeding material using the leaf-stapling technique. This year we have established a large screening area using the infector-row technique. NP(WR)-15, a wilt-tolerant but sterility mosaic-susceptible cultivar, was planted early and inoculated with sterility mosaic. Paired rows of the infector were spaced to permit planting 12 rows of test material in between; and with this spacing, susceptible materials show close to 100-percent infection. Plants not showing symptoms are inoculated by leaf stapling to detect possible escapes.

Screening for wilt and mosaic can be done simultaneously by using infector rows for spreading sterility mosaic in a wilt-sick plot. We consider both of these diseases sufficiently important to give priority to combining resistance to them in improved cultivars. We have determined that the sterility mosaic-resistant lines ICP-3783 and -7035 have field tolerance to wilt and *Phytophthora* blight. ICP-7119 has field tolerance to wilt as well as resistance to sterility mosaic.

Insect Reaction

Levels of insect damage were determined on small plots of 4558 germplasm accessions and larger plots of breeding material under pesticide-free conditions. Differences in cultivars were observed, and those breeding lines with low levels of damage will be retested in large replicated plots. Derivatives of intergeneric hybrids (F_6), previously unselected for insect reaction, gave very interesting results. Groups of lines from crosses involving three species of

Atylosia were compared and podfly and borer damage was least in crosses with *Atylosia scarabaeoides* (Table 28). Some antibiosis in *A. scarabaeoides* to *Heliothis armigera* was also found. When compared with those fed on pigeonpea, the period of larval development was extended and weights were lower in larvae and pupae when the insects were fed on *A. scarabaeoides* (Table 29). In this regard, *A. sericea* was intermediate between *A. scarabaeoides* and the pigeonpea check.

Intergeneric Hybridization

We reported last year that derivatives from crosses of pigeonpea with *Atylosia* species were high in protein percentage. These results were confirmed during the 1976-1977 year. We plan more detailed analyses of the *Atylosia* species themselves and are attempting to make crosses among the species, as well as additional crosses with *Cajanus.* At present we have 10 *Atylosia* species available (Table 30). The most recently collected, *A. cajanifolia,* appears to be the closest wild relative of *Cajanus.* It was collected in the Bailadilla Hills in Bastar district of Madhya Pradesh. *A. rugosa,* also added during the year, was collected near Ootacamund in Tamil Nadu.

Screening for Soil Factors

Screening for waterlogging tolerance under field conditions was unsuccessful. Chambers have been constructed for this purpose, and tech-

Table 28. Pest damage in derivatives of intergeneric hybrids (F_6) grown without insecticide use.

	Borer-damaged pods	Podfly-damaged pods	Mean plant yield
	(%)	(%)	(g)
C. cajan x *A. lineata*	59.8	6.4	5.2
C. cajan x *A. scarabaeoides*	50.4	6.1	6.9
C. cajan x *A. sericea*	56.3	8.1	8.0
Pigeonpea check	57.5	17.4	12.7

Table 29. Development of *Heliothis armigera* Hub. immature stages feeding on *Atylosia scarabaeoides, A. sericea,* and a pigeonpea check.

Food plant	Larvae[a]			Pupae[a]	
	3rd instar length	Larval weight	Larval-development period	Weight	Pupal period
	(cm)	(mg)	(days)	(mg)	(days)
A. scarabaeoides	2.3	133.4	31.8	186.1	12.9
A. sericea	2.7	201.3	29.5	209.3	13.8
Pigeonpea check	3.2	321.8	26.8	276.8	13.9

[a]Average of 12 insects.

niques will be tested for reliability of results. Preliminary work is in progress on development of precise screening for salinity tolerance.

Ratooning

Last year we reported increased production by ratooning. Pigeonpeas are normally harvested when the pods mature. However, if the plants are left in the field they go on to produce a second flush of flowers and a second crop of pods. This second crop is produced during the hot dry season when the fields cannot be used for other crops; the well-established deep root system of the pigeonpeas is able to exploit water which is still available in the soil.

The first crop of pods can be harvested by cutting off the pod-bearing branches; the ratooned plants then go on to produce a second crop. The ability of cultivars to produce a good second crop after ratooning differs considerably, but some are able to produce almost as much in the second crop as they did in the first.

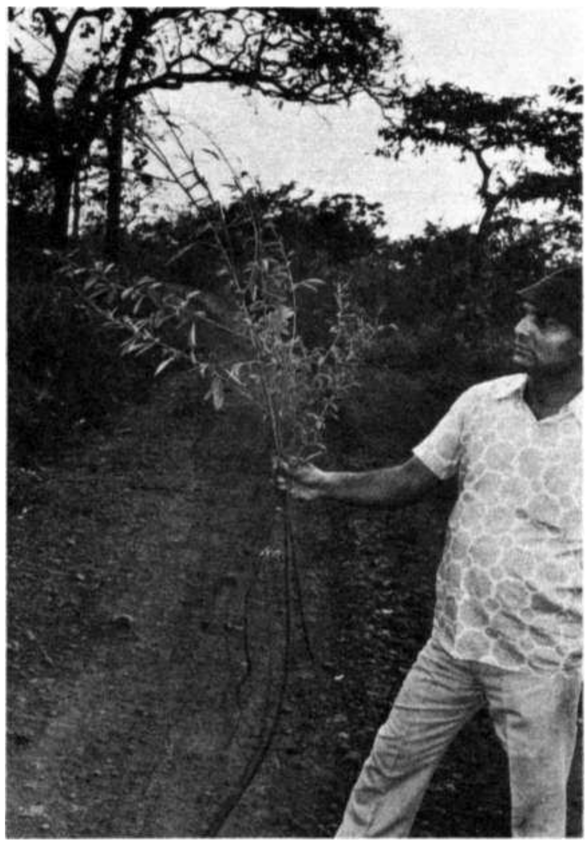
We have investigated the effects of different ratooning treatments, at the time of the first harvest, on second-harvest yields. When the plants were ratooned progressively lower down, closer to the ground, there was more regenerative vegetative growth before they again began flowering. Plants which were not ratooned at all, from which the first crop of pods had been plucked by hand, were first to begin flowering again and they produced a second crop of pods sooner than any of the ratooned plants. These nonratooned plants produced the highest second-harvest yields. The lowest yields came from plants which were ratooned closest to the ground.

These results clearly showed that the best treatment of all was nonratooning, pfobably because the second crop of pods was produced with the minimum delay at a time when water stress was becoming progressively greater. The yields obtained were quite considerable. For example, in an experiment on a deep Alfisol cv 148 and AS-71-37 produced a mean second-harvest yield of 1 000 kg/ha without ratooning,

Table 30. *Atylosia* species available at ICRISAT Center.

Species	Entries
A. scarabaeoides	12
A. sericea	3
A. lineata	3
A. platycarpa	1
A. volubilis	2
A. trinervia	1
A. grandifolia	1
A. albicans	3
A. cajanifolia	1
A. rugosa	1

Figure 27. Plants of Atylosia cajanifolia, *apparently the closest wild relative of pigeonpea, collected in Bailadila Hills of Madhya Pradesh, India.*



compared with 500 kg/ha when ratooned at a height of 60 cm. The mean yield during first harvest was 1 200 kg/ha. Hence the second-harvest yield without ratooning was more than 80 percent of the yield of the first harvest, which emphasizes the importance of attempting to exploit the second-harvest potential of pigeon peas.

Pigeonpea as a Winter Crop

In India, pigeonpeas are normally planted at the beginning of the rainy season (Jun/Jul). Medium-duration cultivars take about 5 to 7 months to mature and late cultivars more than 7 months. The flowering of medium- and long-duration cultivars of pigeonpeas is inhibited by the longer day lengths of the summer and the early part of the rainy season; they are photoperiod sensitive "short-day" plants. If they are planted at the beginning of India's winter season (Oct) they flower and mature sooner because of the shorter day length during the winter season; there is less growth because of the cooler weather.

Last year we found that pigeonpeas could be grown successfully as a nonirrigated winter crop. Because the plants are much smaller than usual they can be grown at much higher population densities than in the normal season. This year we carried out a more-detailed trial to investigate the potential of pigeonpeas as a winter crop. Early, medium-, and late-maturing cultivars were compared. Although the late types were the last to mature. they matured in just under 5 months compared with more than 7 months in the normal season; the medium-duration cultivars matured in $4^1/_2$ months and the early cultivars in 4 months. The early cultivars gave the lowest yields and the medium-duration cultivars the highest. Of these, cv C-11 was the best with yield of more than 1 700 kg/ha; cv ICP-1 gave 1 500 kg/ha compared with only 1 300 kg/ha in the normal season. These results indicate the considerable potential of pigeonpea as a winter crop.

Figure 28. Cultivar differences in response to soils waterlogged for 6 days in chambers (on right) contrasted with normal growth on well drained soils (on left).

Figure 29. Screening for salt tolerance. In upper photo, four cultivars grow in normal field soil; the cultivars below show a differential response to added salts (40 meq/kg soil).

Figure 30. Pigeonpeas planted in the postrainy season are competitive in yield with full-season pigeonpeas planted in June or July. Cultivars of different maturity are shown in an experiment in which effects of planting date and spacing are also studied.

Observations showed that nodulation and nitrogenase activity of these winter-sown pigeonpeas was much poorer than on those sown in the rainy season. At 40 days after planting, nodules per plant ranged from 6 for cv 7065 to 17 for cv C-II, which also had the greatest nitrogenase activity of 4.68 µ moles C_2H_4, plant per hour. Nodule efficiency - nitrogenase activity per unit nodule weight - was also much lower than for the rainy season planting, with most activity at 40 days (133 µ moles C_2H_4/g dry nodule per hour for C-11). By 70 days, nitrogenase activity was virtually nil. Insect grubs also attacked nodules on this winter crop.

Residual Effects of Pigeonpeas on Subsequent Crops of Pigeonpea

Last year we found that when pigeonpeas were grown in soil where pigeonpeas were grown the previous year, the plants were stunted and unhealthy and gave very poor yields. This year we observed the same effect in some, but not all, parts of ICRISAT Center. Other crops such as sorghum, millet, and castor were unaffected. This deleterious effect on pigeonpea growth could not be brought about by adding pigeonpea residues to normal soil, nor was the effect reduced by removing pigeonpea residues from soil when pigeonpea had been grown previously. Therefore a toxic effect of pigeonpea residues can be ruled out. We now have some preliminary evidence that the harmful effects might be explained by the build-up of parasitic nematodes. This possibility is being investigated further.

Effects of Nitrogen Fertilizer on Pigeonpea Growth and Yield

Improved cereal pigeonpea intercropping systems will almost certainly involve applying nitrogenous fertilizer to the cereal. We investigated the effects of a starter dose of 20 kg N ha as well as a liberal dose of 200 kg N ha and 20 tons/ha of farmyard manure on the growth. nodulation, and yield of cv ICP-1 grown on Vertisol and on Alfisol. Vegetative growth was increased significantly by 200 kg N ha but nodulation and nitrogenase activity, measured by the acetylene-reduction technique, was surprisingly little affected. In Vertisol at 30 days after planting there were 15 nodules per plant with 21 mg dry weight for the 200 N treatment compared with 29 per plant (52 mg) for no N fertilizer. At 60 days these differences had disappeared. Nitrogenase activity per plant followed the same pattern. Nodules that formed, regardless of the N treatment, were equally efficient in nitrogen fixation per g of nodule.

However by the time of harvest, although the nitrogen-fertilized plants had more stem material and had produced more leaves, there were no significant differences in grain yield. These results indicate that yield was not being limited by nitrogen supply.

Nitrogen fixation by the nodules is apparently adequate for the yield potential of this cultivar at ICRISAT Center. Farmyard manure treatment enhanced nodule activity in the early stages, but had no significant effect on growth or yield.

Seed Size and Seedling Size

The influence of cultivar differences in seed size on seedling growth were investigated with twenty cultivars from seeds with 100-seed weights ranging from 4.5 to 22.2 g. At first there was a close relationship between seed size and seedling size with 100-seed weights of up to about 16 g, but as time went on size of the young plants bore less relation to the size of the seeds from which they were derived (Fig 31). The greater "seedling vigor" of the larger-seeded cultivars could be of importance when seedlings face adverse conditions-such as, for example, surface crusts on Alfisol.

Ovule and Seed Abortion

The extent of ovule and seed abortion during pod development in a range of genotypes was estimated. In some small-seeded cultivars, up to 90 percent of the ovules developed into mature seeds, but in other cultivars more than half of the ovules or young seeds aborted. There was a negative correlation (r = - 0.81**) between the percentage realization of the potential seed number and 100-seed weight.

Pod-set

In previous years we found that pods formed in the later reproductive phase were the same size as those formed earlier. This suggested that pod-set was suboptimal. Cultivars in which pod-set is not limiting yield might be expected *to* show a decline in the average weight of late-formed pods, which would indicate a limitation of nutrient or assimilate supply. We have compared weights of early and late-formed pods in more than 30 cultivars; so far we have found none in which the weight of the later-formed pods shows a distinct and significant decline. This type of measurement seems to be sufficiently simple and reliable for use in screening large numbers of plants from the germplasm collection in an attempt to find cultivars in which pod-set is not limiting the yield, if such cultivars exist.

Source-sink Relationships

Flower Removal

Experiments were carried out in the field to extend last year's observations of the effects of experimentally delayed pod-set on yield. Using the early and medium-duration cultivars, we found that when all flowers were removed from the plants for 1 to 7 weeks, there was no significant reduction in yield in any of the cultivars. This ability to compensate so well for the loss of early formed flowers and pods is probably of considerable importance in enabling

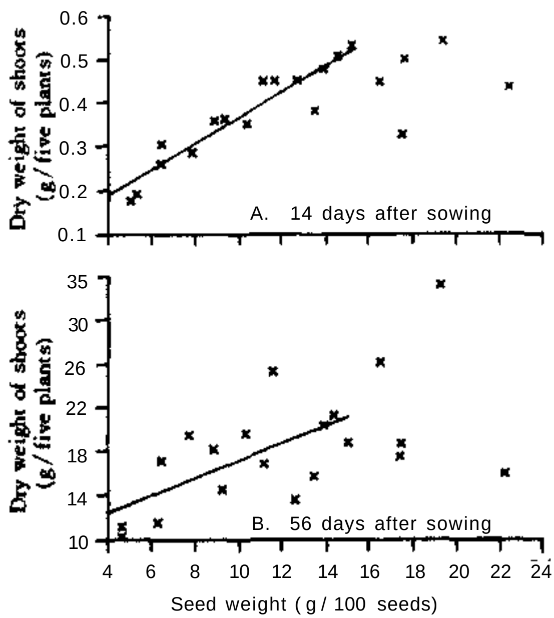


Figure 31. Relationship between 100-seed weight and total dry weight of seedling shoots of 20 pigeonpea cultivars.

the plants to produce some yield under unfavorable environmental conditions and also to withstand insect attacks; it has important implications for the development of minimum-input pest-management systems.

Effects of Defoliation

Last year, which was an unusually wet year with late rains, we found that removing different proportions of the leaves from the plants throughout the reproductive phase led to proportionate decreases in yield. This year the rainy season ended unusually early and as a result growth and yields were reduced. Under these conditions, with four different cultivars, we found that half or more of the leaves could be removed throughout the reproductive phase without affecting the yield significantly. Data for cv ICP-1 are plotted in Figure 32. These results indicate that leaf area was not limiting pod-set and yield. The difference from last year's observations suggests that under conditions of moisture stress the photosynthetic efficiency of the leaves may be limited by water supply; perhaps the removal of half the leaves results in an increased water supply to the remaining leaves and an increase in their photosynthetic efficiency.

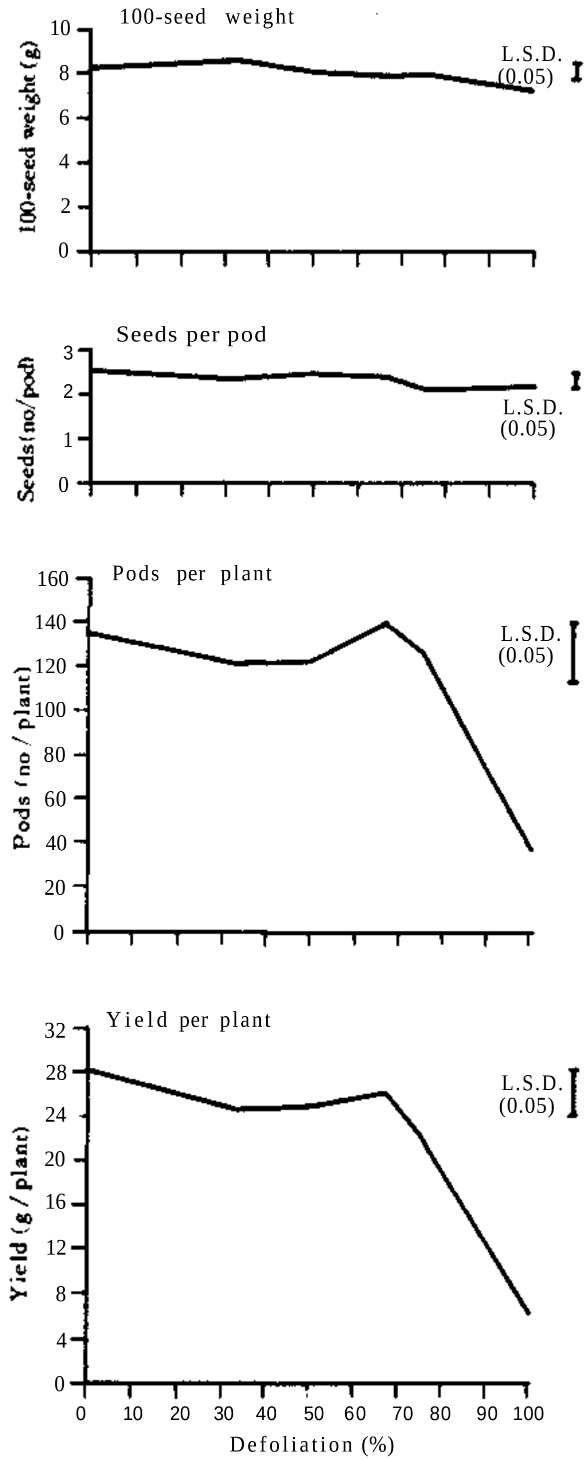


Figure 32. Effect of different degrees of defoliation throughout the reproductive phase on yield and yield components of cv ICP-1.

Diseases and Pests

Fusarium Wilt

In our continued studies of the wilt disease, we found three pathogenic Fusarium species associated with wilted plants: F. udum, F. oxysporum, and F. solani. Twelve distinct cultural isolates of F. udum, and two each of F. oxysporum and F. solani are being maintained for further studies.

Preliminary studies indicated that F. udum colonized roots of pigeonpea plants in the sick plot between 16 and 30 days after planting. The pathogen could be detected in the plants prior to the appearance of wilt symptoms. In infected plants, F. udum was isolated from the root, stem, branches, and pod hulls, but not from seed. The fungus remained restricted to the underground parts of plants not showing wilt symptoms. Two distinct types of symptoms-wilting with and wilting without a necrotic band on the stem - were observed.

Our observations of the past 3 years at 1CRISAT Center indicate that the appearance of wilt symptoms increases rapidly from November onwards. We have started studies of the yield loss in relation to time of wilting, and preliminary results show a progressive decline in losses with symptoms appearing in successively later stages of pod formation and development. Surveys of disease incidence may tend to overestimate yield losses if seed production on diseased plants is ignored.

Sterility Mosaic

The causal agent of this disease has not yet been identified. We have been unable to transmit the disease either by mechanical transmission or by grafting. In the case of diseases caused by a mycoplasma-like organism, treatment with tetracycline has been found to give remission of symptoms. Tetracycline applications, made in several ways, had no effect on symptoms of plants infected with sterility mosaic. Electron microscope observations to date have not revealed virus or mycoplasma-like drganisms.

Although the organism has not been identified, the vector has been known for several years. Our studies have shown that a minimum 30-minute inoculation-access period was required for transmission by the mite (*Aceria cajani).* A single mite can transmit the causal agent.

Although infected plants are usually sterile, seed is sometimes produced and we have grown several thousand seeds from diseased plants. In no case has sterility mosaic been transmitted through the seed; we consider that the causal agent is not seed-borne.

Disease Surveys

Surveys are being made each year to assess losses in farmers' fields. This year the central and western districts of Maharashtra, not included in our previous survey, and the states of Karnataka and Tamil Nadu were surveyed. Wilt and sterility mosaic were found to be the most important diseases, with a very low incidence of root rot and leaf diseases observed. The relative importance of sterility mosaic increased in areas further south (Table 31).

Table 31. Observations of wilt and sterility mosaic in farmers' pigeonpea fields in three states of India, 1976.

State	Wilt		Sterility mosaic	
	Range	Mean	Range	Mean
	— (%) —		— (%)	—
Maharashtra (western & central districts)	0-38	7.6	-	3.9
Karnataka	0-17	1.1	0-95	9.7
Tamil Nadu	0-65	1.4	0-93	12.8

Pest Surveys

The relative importance of various insect pests on pigeonpea was recorded by surveying and sample collection in Karnataka, Tamil Nadu, Maharashtra (Akola and Sholapur districts), Bihar, Orissa, Andhra Pradesh, and Uttar Pradesh. The borer damage ranged from 3 to 84 percent. Severe pod damage was recorded in southern states of India (Table 32).

H. armigera was found to be the major cause of loss in pigeonpea but *Exelastis atomosa* Wals. and *Maruca testulalis* Geyr. were also common as pod borers.

Nutritional Quality

One of our objectives is to improve the nutritional quality of pigeonpea. We recognize that the first priority is to increase production of pulses, so have not included nutritional factors as selection criteria in the breeding program. Emphasis to date has been on screening the germ-

Table 32. Range of pod damage to pigeonpeas caused by different pests in samples collected from various states of India (1975-1977).

State	Species				
	Lcpidopterous borers (*H. armigera, E. atomosa; Maruca testulalis)*	Podfly (*Melanagro-myza obtusa)*	Bruchids (*Calloso-bruchus chinensis; C. maculatus)*	Hymenoptera (*Taraostig-modes* sp.)	Actual pod damage by insects
	(%)				(%)
Uttar Pradesh	2.6-12.3	9.9-36.0	0 - 0 . 2	0 - 0.2	15.5-48.7
Bihar	3.1-31.3	8.5-56.3	0 - 0.7	Below 1.0	15.5-70.6
Orissa	11.8-28.2	23.5-28.1	1.0- 4.4	0.2- 1.9	37.5-52.4
Andhra Pradesh	15.3-67.9	1.1-14.6	0 -22.2	0 -34.3	18.2-71.4
Maharashtra	10.9-83.5	1.8-44.3		0 - 1 . 4	15.5-84.6
Karnataka	3.1-81.1	2.4-19.7	0.9-43.8	0.5-54.1	27.3-88.3
Tamil Nadu	12.4-73.7	0.6-32.6	1.1-46.6	0.7- 4.7	26.1-81.5

plasm for total protein content, and conducting studies on techniques for estimating protein and some of the limiting amino acids. These studies are essential for identifying rapid and economical procedures that will be needed for implementing a breeding program for higher quality.

Comparison of Methods of Protein Estimation

The Kjeldahl method of estimating total nitrogen is considered to be the standard method. The MKJ (micro-Kjeldahl) method gives very similar results, and we have used it as a standard method in our studies. We also use the TAA (Technicon Auto Analyzer) and DBC (dye-binding capacity) methods. We found a very high correlation (r = +0.96) between MKJ and TAA when testing whole seeds. However, the correlation of MKJ and DBC determinations was lower (r = + .87). This lower relationship was attributed to interference of seed coat pigments in the DBC method. Whole seed having the same protein content as dhal samples gave a higher reading on the UDY instrument used in the DBC method (Fig 33).

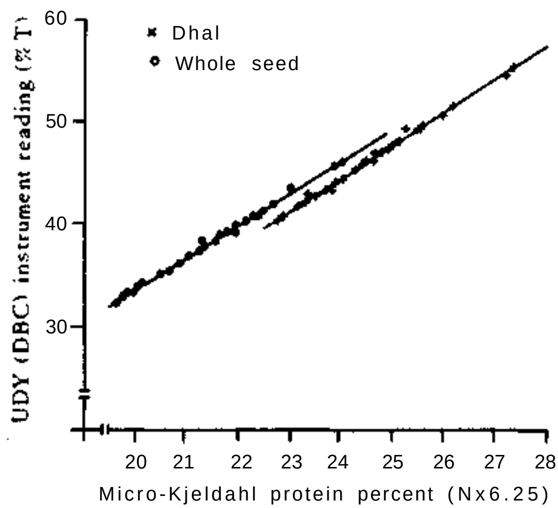


Figure 33. Relationship between DBC method and MKJ procedure in determining protein content of pigeonpea.

When dhal samples were analyzed, both TAA (r= +.96) and DBC (r = +.94) were highly correlated with MKJ. It was concluded that for rapid screening of dhal samples, either DBC or TAA could be used, while for screening whole-seed samples TAA should be used.

Whole-seed Protein vs. Dhal Protein

For rapid screening it would be desirable to use ground samples of whole seed; preparation of dhal of many small samples is tedious and time-consuming. We determined the protein content of dhal and whole-seed samples of 43 cultivars using the MKJ technique, and found a correlation of r = + .94 (Fig 34). The same samples by TAA gave a correlation of r = + .97, and with the DBC method r = +.88. It was concluded that for rapid screening, whole seed rather than dhal samples could be analyzed.

Errors of Determination of Protein

In order to establish reliable procedures for comparing protein content of different pigeonpea lines, we conducted an experiment to compare sources of error. Seed of 10 cultivars grown in three replicates were sampled twice, and these subsamples were each analyzed twice by TAA. The experiment was repeated on 2 different days in the laboratory.

The experimental error (random variations among cultivars in different replicates in the field) was the most important source of error. It was three to four times as large as error due to sampling within seed lots or determination error in the laboratory. The results indicate that reliable estimates of genetic differences in protein cannot be made on individual plants or plots because of interaction with the environment. However, with the three replicates used, it was possible to identify small differences among cultivars.

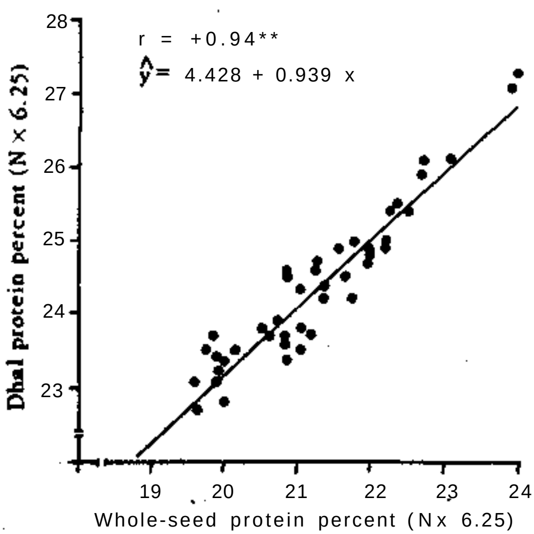


figure 34. Relationship between whole-seed protein and dhal protein in pigeonpea by MKJ method.

Sulphur Amino Acids and Tryptophan

Protein quality of pigeonpea is determined in part by the limiting amino acids. Pigeonpea seed protein is normally low in methionine, cystine, and tryptophan. Microbiological assays for the estimation of sulphur amino acids and the use of the Leco sulphur determinator for the estimation of total sulphur in pigeonpea samples are being tried, in order to understand whether the total sulphur determination would be an indirect useful way to screen for sulphur amino acids. Two colorimetric methods for the estimation of tryptophan are being evaluated for rapid-screening purposes.

Composition of Some Pigeonpea Cultivars

Ten released cultivars of pigeonpea were analyzed for protein, starch, soluble sugars, fat, crude fiber, and ash contents (Table 33). Protein content ranged between 23 to 27.3 percent, whereas starch percentage ranged between 56.3 to 64.1. Fat, crude fiber, and ash contents ranged between 1.2 to 2.2, 1.0 to 1.2, and 3.3 to 4.3 percent respectively.

International Cooperation

We are maintaining a close liaison with pigeonpea breeding programs in India and in other countries. We furnish detailed annual reports *of* our various disciplines to cooperating scientists to keep them abreast of developments prior to formal publication of our results. We also furnish breeding material; 21 breeders from 8 countries were supplied segregating populations

Table 33. Chemical composition of dhal samples of some pigeonpea cultivars, expressed on a moisture-free basis.

Cultivar	Protein	Starch	Soluble sugars	Fat	Crude fiber	Ash	Total
	(%)						(%)
HY-3C	23.1	61.6	5.3	2.2	1.1	3.3	96.6
ICP-1	24.7	61.2	4.8	1.2	1.2	4.0	97.1
ST-1	23.0	61.6	5.2	1.4	1.1	3.7	96.0
No. 148	24.5	63.2	5.7	1.4	1.2	3.9	99.9
T-7	25.9	64.1	5.5	1.4	1.2	3.7	101.8
T-17	27.3	57.7	4.7	1.7	1.2	4.1	96.7
T-21	24.6	59.0	5.3	1.5	1.1	4.0	95.5
BDN-1	24.2	60.8	5.4	1.8	1.0	3.9	97.1
C-11	24.3	61.8	5.1	1.5	1.2	4.2	98.1
Gwalior-3	26.6	56.3	5.0	1.5	1.2	4.3	94.9

and selected lines. Many requests for cultivars to be tested for local adaptation have been filled; requests have ranged from types for grain production to specialized types for forage production or for use as windbreaks.

Looking Ahead in Pigeonpea Improvement

We now have quantitative evidence showing that pod-set is limiting pigeonpea yields; this conclusion was generally accepted before such data were available. However, we now have a simple screening technique for identifying genotypes in which pod-set is not limiting. All genotypes examined so far are limited by pod-set; we will screen the germplasm and segregating material for the exceptional types.

Disease-screening techniques now available make possible a shift in emphasis in the breeding program. Where we have been selecting for yield in early generations, we can now screen for resistance to wilt, sterility mosaic, and phytophthora blight resistance sequentially, and defer selection for yield until more advanced generations when apparent heritability is higher.

Sick plots for disease screening are being developed to permit simultaneous selection for resistance to more than one disease.

The possibility of utilizing F^1 hybrids in commercial plantings will be studied intensively in the immediate future. In addition to yield advantages, hybrid utilization can be expected to result in wider adaptation and would facilitate the combining of desired characters directly in genotypes for planting by farmers.

Additional emphasis will be placed on developing methodology for screening for insect resistance. Evidence of antibiosis in wild species of *Atylosid* indicate the need for identifying specific factors that can be transferred by breeding.

It is clear that the total supply of pulses can best be increased through improved yields. However, since they are a source of protein in the diet, we will attempt, through intercrossing, to develop unusually high protein lines. These will be examined for protein quality before high protein is included as a primary selection criterion.

We will encourage wide-scale testing of pigeonpea as a postrainy season crop, utilizing medium-late rather than early cultivars; early planting has given postrainy season yields higher than those of the rainy season for some cultivars.

The scope and limitations of taking a second grain crop from short- and medium-duration cultivars planted in the rainy season will be studied intensively; this appears to be a good possibility for increasing production without additional inputs.

The possibility of cropping Vertisols which are normally fallowed in the rainy season by including pigeonpea as a component in the preceding postrainy season cropping combination and permitting it to continue into the rainy season will be further investigated. The payoff in increased rainy season cropping could be tremendous.

International testing will continue to expand as advanced lines are developed. The first ICP selection nursery was distributed for planting in the coming season. Consisting of 38 advanced lines selected for large seed for possible use as vegetable types, it was sent to 16 locations in 11 countries.

CHICKPEA

Chickpea

The objectives of the chickpea improvement program are: (i) to develop high-yielding disease- and pest-resistant cultivars with good grain quality, (ii) to furnish advanced breeding lines and segregating populations to national and local breeding programs, and (iii) to support regional and national programs through exchange of information, germplasm, and training of personnel.

Chickpea is a relatively short-season crop, maturing in approximately 4 months at ICRISAT Center and in a slightly longer time at Hissar in northern India. Thus there is ample time for growing two generations per year, but the climate at ICRISAT Center and Hissar does not permit growing a second generation. For 2 years we grew the second generation in Lebanon, but unsettled conditions there and problems in processing so many samples through quarantine forced us to discontinue. We also utilized the Lahaul Valley in northern India for off-season advance, but the growth conditions were less than optimum and there was also a problem of acquiring land; we abandoned that location after the 1976 crop. We are presently growing off-season test plantings at three sites in Kashmir, hoping to find a location to supplement the work at ICRISAT Center and at Hissar. Research in breeding, physiology, and germplasm evaluation has been carried out at both of the above locations; research in pathology, entomology, and microbiology has been concentrated at ICRISAT Center.

Germplasm Resources

We now have 11140 accessions of *Cicer arietinum* L. Figure 2 shows the geographic origin of the accessions. During the year, collection trips were made in Afghanistan and in India - in the states of Gujarat and Maharashtra, and the eastern area of Uttar Pradesh. A number of accessions were contributed by colleagues. A summary of new accessions is listed in Table 34.

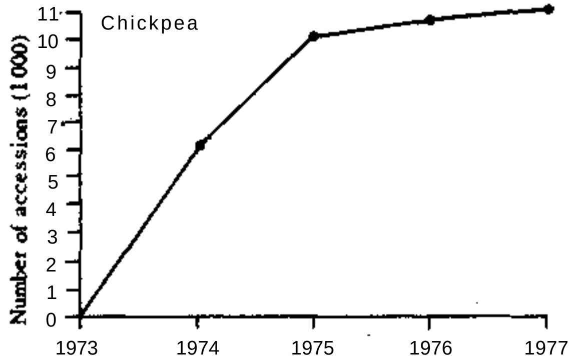


Figure 35. Chickpea germplasm accessions at ICRISAT Center.

Table 34. Chickpea germplasm accessions obtained in 1976-1977.

Source	Entries
Agricultural Research Station, Badnapur, Aurangabad, India	29
Survey collection from Afghanistan	30
Agricultural Research Station, Wagga, Australia	19
Agricultural Research Station, Arnej, Ahmedabad, India	12
Survey collection from Gujarat and Maharashtra, India	133
Survey collection from Eastern U.P., India	49
All-India Pulse Workshop	24
Total	296

Evaluation and Maintenance

Germplasm accessions planted during the year were evaluated primarily for disease resistance, although this was not our original purpose. The field planted at ICRISAT Center turned out to be a hot spot for *Fusarium* wilt, and approximately half of 3784 lines planted were diseased. Observations on 24 morphological and yield characters could be recorded properly for only 850 accessions. At Hissar, only 67 of 2 363 accessions planted remained free of stunt. However, it was possible to record full data on 615.

A total of 181 promising lines were grown in replicated tests for more precise evaluation; harvest index ranged from 14.5 to 70.8 percent and flowering duration from 24 to 66 days at ICRISAT Center.

Seed Distribution

Requests were filled as indicated in Table 35. In addition, 8 591 samples were utilized by other disciplines within ICRISAT.

Breeding Program

Hybridization

Our crossing block consists of lines selected from the germplasm and is a working collection for the breeding program. This year there were more than 300 strains selected for various traits, including high yield, plant type, maturity period, seed size, podding habit, disease resistance, protein content, wide adaptation, and other special characters. Based on performance, a number of lines are dropped each year, and others are added from the germplasm pool.

Table 35. Chickpea germplasm supplied to research agencies in India and other nations during 1976-1977.

Institution	Location	Entries
INDIA:		
Osmania University	Hyderabad, A.P.	10
Kakatiya University	Warangal, A.P.	20
Haryana Agricultural University	Hissar, Haryana	106
Regional Research Station	Raichur, Karnataka	37
IARI	New Delhi	55
Agricultural Research Station	Nayagarh, Orissa	7
Punjab Agricultural University	Gurdaspur, Punjab	226
Punjab Agricultural University	Ludhiana, Punjab	363
Tamil Nadu Agricultural University	Coimbatore, Tamil Nadu	50
Chandra Shekar Azad University of Agriculture & Technology	Kanpur, U.P.	53
Banaras Hindu University	Varanasi, U.P.	1000
OTHER NATIONS:		
University of Ottawa	Canada	9
Mr. Guitierrez	Palmira, Colombia	10
University of Reading	England	24
Centre National de Recherches Agronomiques	Versailles, France	12
Minor Irrigation Project, FAO	Nakuru, Kenya	10
Agricultural Research Centre, C/o UNDP	Tripoli, Libya	20
Department of Scientific and Industrial Research	Christ Church, New Zealand	15
ICARDA	Syria	10
Chief Agricultural Research Officer	Lusaka, Zambia	50

During the past year 2 000 crosses among these selected parents and among hybrids were made. In the nurseries at ICRISAT Center and at Hissar we grew a total of 14244 segregating populations and progeny rows for selection.

Selection for High Yield

Emphasis in selection has been on high yield. Pedigree selection at the two breeding sites has provided an opportunity to find segregants adapted to two diverse environments. Inferior progenies can be rejected on the basis of visual observation, but because of differential pod filling, variation in seed size, and the quantity of material involved, it has been necessary to make final selections among the best lines on the basis of yield measurements. Frequent checks are used for comparison with the progeny rows, which are not replicated.

Breeding for Plant Type

Chickpea has a relatively high harvest index, and the desi types are considered to be efficient producers. These are relatively short cultivars, and we are investigating the possibility of increasing plant height as a means of providing more sites for pod production. A comparison of yields of some check cultivars and selected F_3 progenies is given in Table 36. Relative yields per plot show that the tall parents were not adapted to Hyderabad conditions. We are pleased with the performance of the F_3 lines, since it has been possible to select some that are superior in yield to the adapted check (Annigeri). We have made some backcrosses to the high-yielding parent, and expect the introduction of more genes from the locally adapted parent to produce higher-yielding segregates.

Diseases of Chickpea

Before breeding for disease resistance could be initiated, knowledge of the importance and distribution of chickpea diseases was necessary. During the last three seasons extensive surveys

Table 36. Comparative performance of normal and tall chickpea cultivars and their F_3 progenies during 1976-1977 at ICRISAT Center (yield based on single meter-length rows, not replicated).

Cultivar/progeny	Height	Maturity[a]	Yield
	(cm)		(kg/ha)
Dwarf parent			
Annigeri	30-35	E	2654
G-130	35-40	L	2371
Tall parent			
K-1184	65-70	VL	499
K-1481	65-70	VL	747
F_3 progeny			
H-208 x K-1258(-37)	54	M	3448
K-4 x K-56567(-18)	60	M	3144
F-378 x K-1184(-28)	60	M	2995
H-208 x K-1258 (-34)	55	M	2931
Annigeri x K-1480 (-35)	51	M	2816

[a]E = early, M = medium, L = late, VL = very late

were carried out, particularly in India. The locations included several experiment stations and farmers' fields in India, Ethiopia, Iran, Lebanon, Syria, and Turkey.

In India three diseases seem to predominate. These are stunt (cause considered to be a virus), wilt caused by *Fusarium oxysporum,* and root rot caused by *Rhizoctonia bataticola.* Other causes of drying/wilting include fungi such as *F. solani, R. solani, Sclerotium rolfsii, Sclerotinia sclerotiorum, Operculella padwickii;* a mosaic virus; termites; root-knot nematode; lack of moisture; salinity; and frost damage. In Iran (at Karaj), chickpea stunt was common and bean yellow mosaic and alfalfa mosaic viruses were also present. In Turkey, traces of root rot by *R. bataticola* and stunt were observed, but the major problem was *Ascochyta* blight. In Ethiopia, stunt was the major problem around Debre Zeit. In Syria and Lebanon, *R. bataticola* root rot, stunt, and *Ascochyta* blight were observed.

On the basis of our intensive studies it is now possible to state that there are distinct diseases which can be considered as components of the so-called "wilt complex." It is now possible to diagnose, without much difficulty, these different diseases; the ultimate effect of the complex is premature drying of plants. A pamphlet describing and illustrating these diseases will be published by ICRISAT; it should be a useful diagnostic aid.

Breeding for Disease Resistance

A wilt (*Fusarium oxysporum* f. sp. *ciceri*) sick plot and a multiple-disease sick plot were developed for screening. By growing crossing block entries (more than 450) in the multiple-disease sick plot, it was possible to identify about 60 promising lines or cultivars. The laboratory technique (water-culture) for wilt screening was improved further and a good correlation noted between field and laboratory results. Preliminary indications of the existence of races of *F. oxysporum* have been obtained.

More than 1200 germplasm accessions, crossing Mock entries, and wild *Cicer* species were screened for *Ascochyta* blight resistance by inoculating seedlings in an Isolation Plant Propagator. Of these, more than 40 cultivars or germplasm accessions were found promising (rating 3 to 5 on a 9-point scale). Two wild species which showed resistance were *Cicer reticulatum* and *C. anatolicum.*

With the successful screening in the wilt-sick plots this past year, plans are being made to screen breeding lines in the coming season. There is a backlog, on which screening will be initiated, of material in F_1 to F_5 generations from crosses involving resistant parents.

Seed-borne Fungi

The genera of fungi isolated from nonsterilized cv JG-62 seed were *Alternaria, Aspergillus, Curvularia, Fusarium, Penicillium, Phoma, Rhizoctonia bataticola,* and *Rhizopus.* Only *Fusarium* and *Alternaria* were isolated from surface-sterilized seed. The germination percentages of nonsterilized and surface-sterilized seed were 82 and 94, respectively.

Fusarium oxysporum was found internally seed-borne. Anatomical studies revealed that at least one of the locations of *Fusarium* in seed is the hilum region. Cultivars varied in the extent of carrying seed-borne inoculum. Of JG-62, P-436, and Chafa, Chafa carried much less inoculum through the seed.

Seed treatment with Benlate-T (0.15 %) (Benomyl 30% and Thiram 30%) eradicated *Fusarium* completely, and eliminated almost all other fungi.

Rhizobium Nodulating Chickpea

Chickpea rhizobia are known to nodulate only *Cicer* spp. At present there is no reliable method of counting their numbers in soil. We can now nodulate chickpeas growing in axenic culture, using a sand:vermiculite root medium enclosed in 22- by 200-mm test tubes, and hope that such a system can be used for a soil dilution-plant infection method of counting chickpea rhizobia.

We have 160 isolates from chickpea nodules collected in India and western Asia, with 60 of

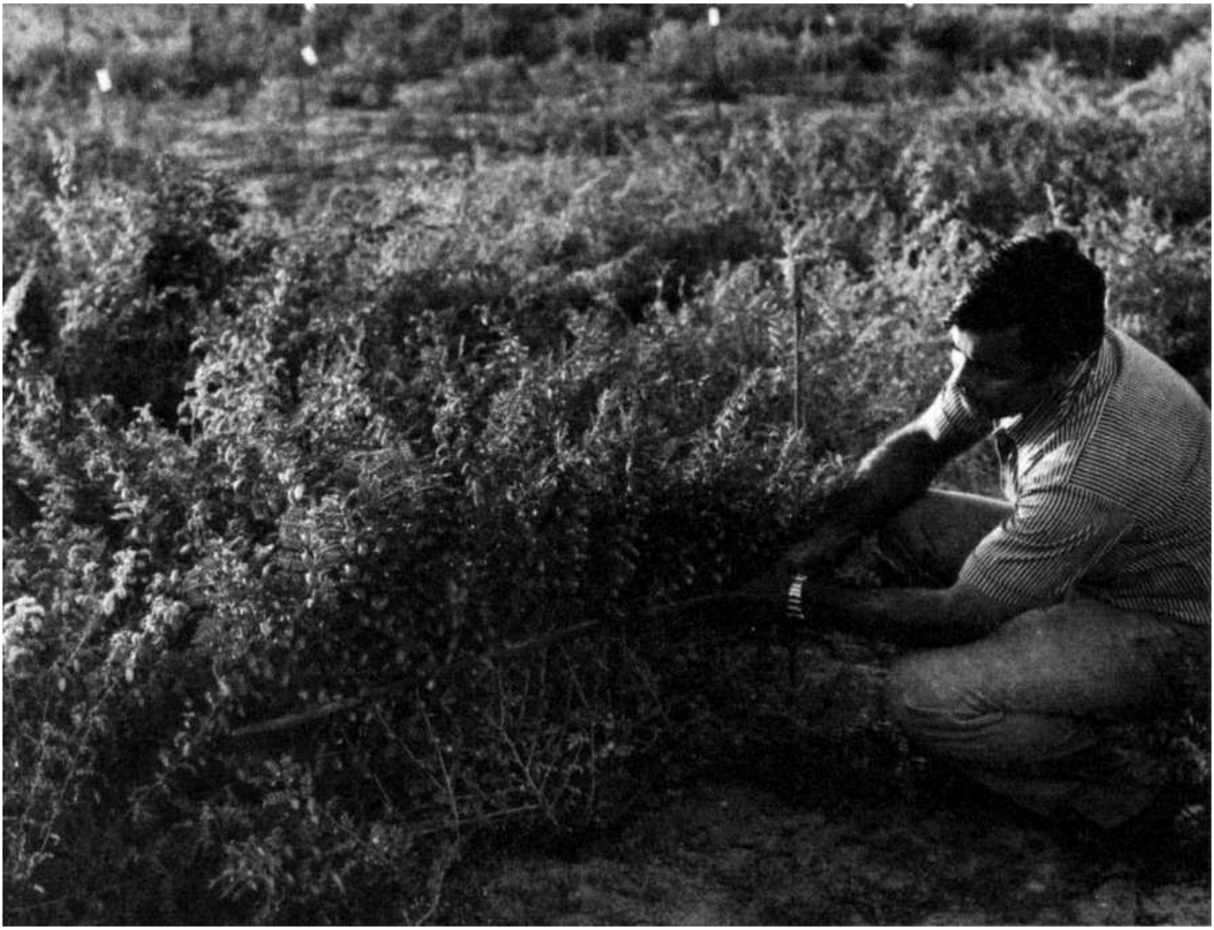


Figure 36. A promising row of chickpea in the breeding nursery where disease losses are heavy, as evidenced by blank areas in the field.

these verified as *Rhizobium.* There are large differences among these strains in nodulation and nitrogen fixation, and field-inoculation trials indicate an interaction among strain, soil type, and host cultivar. When chickpea *Rhizobium* is absent from the soil, seed inoculation produces a marked zonation of nodulation, with nodules forming on, or close to, the primary root in a band from the seed to 12 to 15 cm below it. In soils containing chickpea *Rhizobium* populations, nodules form initially on the primary root, but then also form on the secondary roots.

Nodulation and Nitrogen Fixation

Large areas of chickpea are sown following rice. At ICRISAT Center, chickpea after rice responded to inoculation with an increase in nodulation, nitrogen fixation, and a 64-percent increase in grain yield (Table 37). Uninoculated plants formed virtually no nodules. Inoculated plots yielded 1 800 kg/ha, as did plots given a large application of N fertilizer, indicating that N_2 fixation by nodulated plants was adequate.

Five cultivars of different duration were compared at ICRISAT Center. At only 17 days after sowing, there were differences in nodule number per plant. Nodule number and nodule weight per plant, as well as nitrogenase activity measured by acetylene reduction assay, increased up to the 61st day but declined by the 81st day due to nodule senescence. Nodule weight per plant

Table 37. Yield of chickpea following rice at ICRISAT Center, 1976.

Treatment	Dry matter	Grain
	(kg/ha)	(kg/ha)
Control	1483	1090
Inoculated+150 kg N/ha	2391	1762
Inoculated	2679	1801
L.S.D. (0.05)	364	278
SE±	161	123
C.V. (%)	7.4	7.9

increased sixfold between the 27th and 61st days, mainly through growth of already-formed nodules. Nitrogenase activity over this same period increased fourfold. Nodules were most active per unit of nodule tissue at the time of the first assay (at 17 days) and there was little difference among fanes. The medium-duration desi cv 850-3/27 formed the largest number of nodules and the most nodule tissues. From the 17th day on, it had more than double the number of nodules of the other cultivars. These nodules also had the greatest nitrogen-fixing activity (43 μ moles C_2H_4/plant per hour at 61 days) and 850-3/27 was the only cultivar retaining any nitrogenase activity at 81 days (5 *μ* moles/plant per hour). This cutivar also yielded significantly more than did the other four cultivars.

There was a marked diurnal periodicity in nitrogenase activity, with activity increasing rapidly from 0600 hours until about 0900, and then declining rapidly, with a smaller secondary peak at 1800 hours. Soil temperature apparently had little effect on this pattern.

We surveyed the nodulation of 258 entries in the working collection of chickpea germplasm used in the breeding program at ICRISAT Center. Nodule number and weight per plant varied significantly among lines. A few cultivars had high nodule numbers per plant at both the 18th and 50th days after planting. Some cultivars could be identified as having consistently high or low nodulation. Among cultivars, numbers ranged from 8 to 97 per plant at 50 days after sowing, with nodule dry weight ranging from 2 to 105 mg/plant. A survey of 200 germplasm lines indicated that nodule number per plant was greater at Hissar; nodules there also remained active longer.

Nodules at ICRISAT Center were attacked, apparently by insect grubs. The pest concerned and the consequences of the damage will be investigated.

Comparative Growth and Development

We compared the growth and development of a number of chickpea cultivars at ICRISAT Center and at Hissar. As usual, the yields at Hissar were considerably higher than those at ICRISAT Center. For example, the cultivar which performed best of all in our trials at ICRISAT Center, cv 850-3/27 (which is of medium-duration), yielded 2029 kg/ha; its yield at Hissar was 3413 kg/ha. Patterns of accumulation of dry matter during the reproductive phase, in the entire shoot system as well as in the pods of this cultivar, are plotted in Figure 37 for the two locations, along with corresponding climatic data. At ICRISAT Center, the plants matured 48 days after flowering began, but at Hissar during the same period (although there was more accumulation of dry matter in the shoot system than at ICRISAT Center), almost no pod formation took place. During this period the maximum and minimum temperatures at Hissar were considerably lower than at ICRISAT Center. At Hissar, the cooler temperature apparently suppressed pod-set and consequently favored vegetative growth; as the temperatures at Hissar rose, both pod development and the rate of growth of the entire plant increased. The maturation of the plants at Hissar took place as the temperature and evaporation rose to levels higher than those encountered during the chickpea-growing season at ICRISAT Center. These and other observations described below indicate that senescence and maturation of chickpeas are accelerated by higher temperatures and/or higher rates of evaporation.

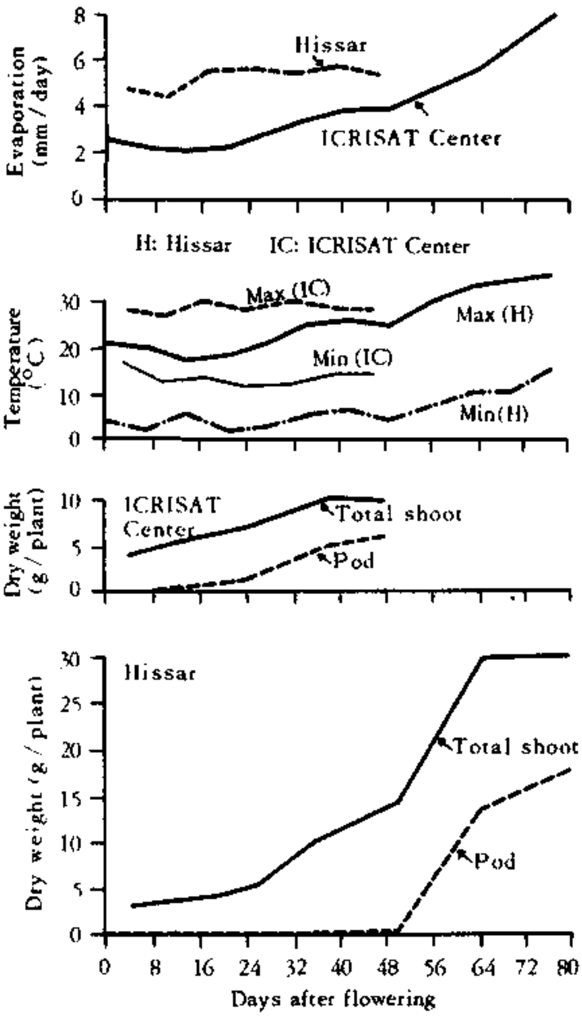


Figure 37. Dry-matter production and pod weight per plant from onset of flowering to maturity in chickpea cv 850-3/27 grown at ICRISAT Center and Hissar. Flowering began on 10 Dec 76 at ICRISAT Center and on 11 Jan 77 at Hissar - 59 and 74 days after sowing, respectively.

Effects of Shading

The effects of shading chickpeas with cloth shades placed horizontally above the crop canopy throughout the reproductive period were investigated. At ICRISAT Center and at Hissar the shading resulted in a striking delay in senescence and maturity. At Hyderabad, shades which cut out 50 percent of the light gave no reductions in yield; on the contrary they generally brought about small increases. Thicker shades, which cut out 80 percent of the light, resulted in significant decreases in the yield of early or medium-duration cultivars planted early in the season, but led to no significant reduction in the yield of cultivars which were maturing late in the season. The senescence-delaying effects of the shades and the actual stimulatory effects of 50-percent shading at ICRISAT Center suggest that the shades were protecting the plants from stresses associated with the heating of the leaves by the sunlight. The stress involved could either be moisture stress (increased by the radiation load and consequent transpiration from the leaves) and/or a direct heat stress. We found that the effects of shading were similar with and without irrigation of the plants, which makes it less likely that the shading effect can be explained in terms of a reduced moisture stress. Also we found that shading had much less senescence-delaying effect and no yield-stimulating effect on winter-grown pigeonpea. (Pigeonpeas are known to be more tolerant to high temperatures than are chickpeas.) Taken together, these results suggest that at least at ICRISAT Center the senescence and maturation of chickpea are accelerated by heat stresses resulting from the radiation load on the canopy.

Source-sink Relationships

Effects of defoliation. Field experiments were carried out at ICRISAT Center this year to investigate the effects of different degrees of defoliation throughout the reproductive phase on yield. Results (mean values shown) for cvs 850-3/27 and Annigeri with and without irrigation are plotted in Figure 38. The yield was reduced roughly in proportion to the degree of defoliation in both irrigated and nonirrigated plants. This yield reduction was largely owing to a reduction in pod number per plant, although there was also a reduction in 100-seed weight, especially after the higher degrees of defoliation. Seed number per pod was affected only very

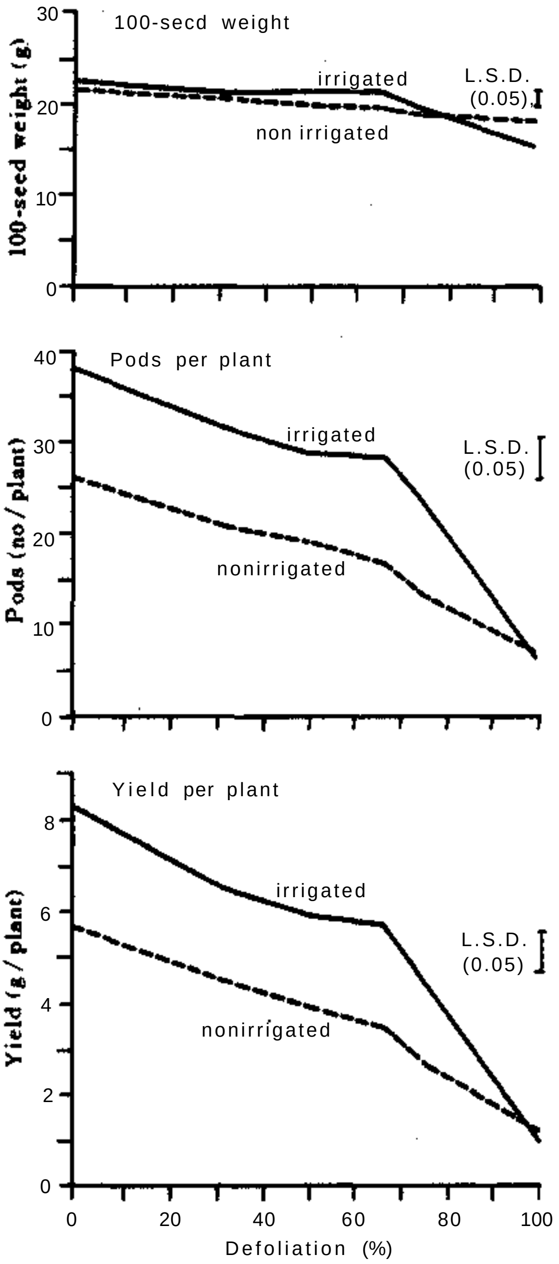


Figure 38. Effect of different degrees of defoliation throughout the reproductive phase on yield and yield components of chickpea cv 850-3/27 and Annigeri (mean values shown) with and without irrigation.

slightly by the treatments. Similar results with cv JG-62 were obtained in a separate experiment.

These results suggest that leaf area was limiting yield. This conclusion contrasts with the results obtained this year in similar experiments with pigeonpea (see p 89 of this report), and also with results obtained last year (1975-1976) with chickpea, when we found that up to 50 percent of leaves could be removed without affecting the yield significantly. Last year the experiments were conducted with plants which were planted late. It seems possible that the discrepancy between the two sets of results may be explained in terms of the effects of moisture and/or heat stresses to which late-planted plants would be more exposed.

Effects of flower removal. This year in experiments with early sown plants at ICRISAT Center we found that all the flowers could be removed from the plants for up to 4 weeks after onset of flowering without causing a decline in yield, if the plants were irrigated. Nonirrigated plants had a significantly reduced ability to compensate for flower removal. Both irrigated and nonirrigated plants were able to compensate more or less completely for the removal of up to 50 percent of the flowers throughout the reproductive period. These compensations involved both an increase in the number of pod-bearing nodes per plant and an increase in the number of seeds per pod.

Last year (1975-1976) we found that flower removal from late-sown plants resulted in a decline in yield and also in total dry matter production. The differences between the 2 years' results might be because of the greater moisture and heat stresses to which the later-sown plants were exposed; these stresses would have limited their ability to continue growing and setting pods.

The "double-podded" Character

Although most chickpea cultivars produce a single flower per node, some produce two flowers and are capable of setting two pods per node. Two pods are formed at only some of the nodes, usually at the more-basal earlier-formed nodes. We confirmed last year's observations that expression of this "double-podded" character is strongly influenced by environment. At Hissar only 3 percent of the pod-bearing nodes of cv JG-62 were double-podded; on early sown plants of the same cultivar at ICRISAT Center, 32 percent of the pod-bearing nodes were double-podded, whereas on later-sown plants this proportion increased to 45 percent. However, at ICRISAT Center the absolute number of double-podded nodes per plant was the same on the early and later-sown plants; the later-sown plants simply had fewer single-podded nodes. The percentage of double-podded nodes at ICRISAT Center was reduced in plants which were defoliated during the reproductive phase. This indicates that the expression of the double-podded character is influenced by the source-sink balance within the plant, but we do not know through which mechanism expression of this character is influenced by environment.

Last year we found - by cutting off the second flower at each flowering node of double-podded cultivars-that the double-podded character conferred a small but significant advantage in yield over plants with only a single pod at each node. We obtained the same result again this year in experiments carried out at ICRISAT Center.

Position of Pods

Last year in an experiment at ICRISAT Center we found that moving the pods into an exposed position above the leaves had no effect on yield. This year we carried out the same experiment with four cultivars at Hissar and again found no significant effect of pod-position on the yield. We can conclude that the "exposed-pod" character is unlikely to be useful in breeding for higher yields.

Cultivaral Differences

Response to spacing. In farmers' fields, stands of chickpea are often poor and patchy. Under conditions where plant stands are variable, cultivars which are more plastic in their response to spacing will yield better than those which are less plastic. We have studied the plasticity of a range of cultivars, using three different methods: by

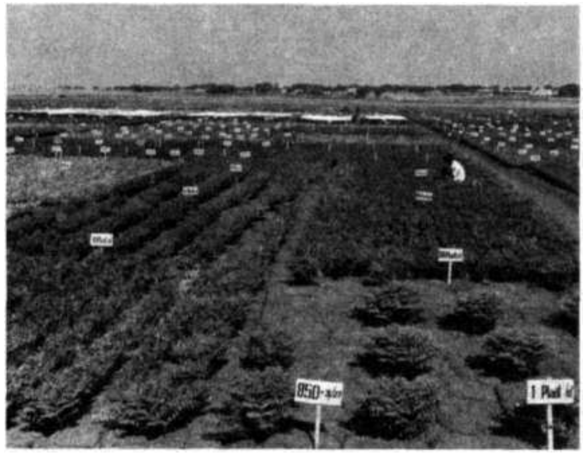


Figure 39. Population density studies identify chickpea cultivars that will compensate for the poor stands frequently encountered by SAT farmers.

comparing yields as the row spacing is systematically increased (in a "fan" design); by comparing yields produced by the border rows of the plots with yields produced by central rows; and in standard plant-population trials with population densities ranging from 8 to 100 plants/m^2. With all methods cultivaral differences were found at both ICRISAT Center and Hissar, but the results from the border-row method did not agree well with the other methods. The differences in plasticity were sufficiently large to suggest that cultivaral performances in standard yield trials may not give reliable indications of yield at lower populations. In a plant population trial at Hissar, for example, cvs G-130 and L-144 at the standard population of 33 plants/m^2 yielded 3 087 and 3 427 kg/ha respectively, while at 8 plants/m^2 their respective yields were 3 043 and 2 200 kg/ha; cv L-144 was much less plastic in response to population density than was cv G-130, and the relative performance of the two cultivars was reversed.

Seed size and seedling growth. We compared the growth of the seedlings of 23 cultivars from seeds ranging in 100-seed weight from 4 to 30 g. There was a close and highly significant relationship between 100-seed weight and the dry weight and leaf area of the seedlings at 16 days after sowing (r = 0.82**), but by 30 days after sowing the relationship was less close (r = 0.57**) (Fig 40). The larger-seeded cultivars also had larger leaves (r = 0.86** for the relationship between maximum area per leaf on 80-day-old plants and 100-seed weight). There was no significant relationship between 100-seed weight and total dry weight at harvest (r = 0.07) or yield (r = 0.13).

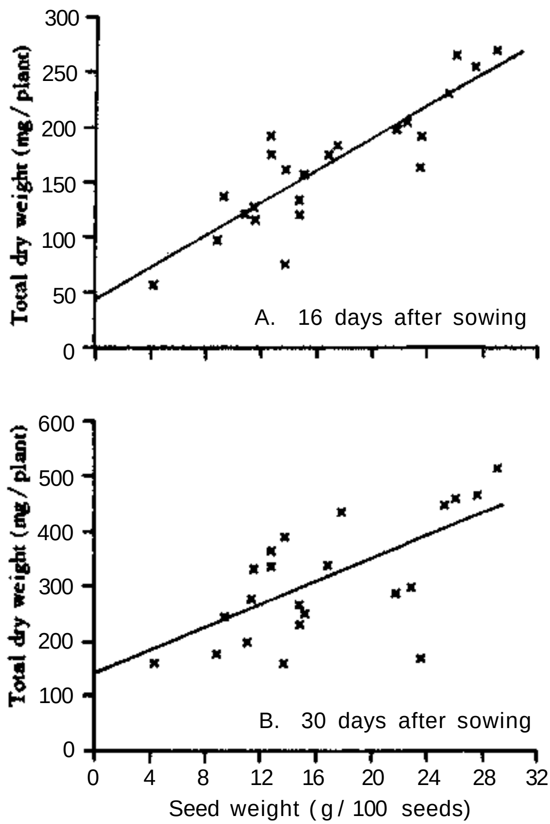


Figure 40. Relationship between 100-seed weight and total dry weight of seedlings of 23 chickpea cultivars.

Susceptibility to iron chlorosis. A number of cultivars grown at ICRISAT Center showed a marked yellowing of the younger leaves during the vegetative phase. The plants recovered spontaneously later in the growing season. The yellowing symptoms could be relieved by sprays of ferrous sulphate, indicating that the symptoms were those of iron chlorosis. In a trial with two iron-chlorosis-susceptible cultivars we found that the sprayed plants gave 35 percent more yield than the controls, showing a distinct yield-reducing effect of this undesirable cultivaral characteristic.

Response to moisture stress. We made a preliminary attempt to identify drought-tolerant cultivars of chickpea by growing 71 diverse cultivars on soil of limited moisture-holding capacity (an Alfisol). Three sets of replicated plots were irrigated during the growing season and three were not. Plants in the irrigated plots matured later and, on average, produced about three times as much dry matter and yield as did the nonirrigated plants, indicating that the latter were subjected to quite severe moisture stress.

Duration of the cultivars (measured by the number of days to flowering) was significantly negatively related to the yield under nonirrigated conditions (r = -0.39**), but was not significantly related to the yield under irrigation (r = 0.04). The ratio of the yield without irrigation to the yield with irrigation (which can be regarded as an index of drought tolerance) was significantly negatively related to the number of days to flowering (r = -0.33**). In other words, the earlier cultivars tended to be more drought-tolerant and to yield better under nonirrigated conditions than did the later cultivars, but this tendency explained only a small part of the cultivaral differences.

Although the correlations between yield per plant with and without irrigation (r = 0.60**) and between yield per plant without irrigation and the "drought-tolerance index" (r = 0.48**) were significant and positive, they are not strong enough to effectively identify-on the basis of yield under conditions of adequate moisture - cultivars which would yield well under drought conditions. Nor can plants which are most "drought tolerant" (as judged by ratio of yield without to yield with irrigation) be reliably identified simply by the yield produced under moisture stress.

Growth Studies in Controlled Environments

Our field studies on growth of chickpea are being supplemented by work in the Plant Environment Laboratory at Reading University in England. Under a collaborative project financed by the Ministry of Overseas Development, R. J. Summerfield and his colleagues have completed initial experiments in which several cultivars were grown to maturity in controlled environments. With appropriate light sources, the plants closely resembled those grown in the field in India. At present an experiment involving different day and night temperatures and daylengths is in progress; this has already revealed very marked and distinct effects of both day and night temperatures.

Table 38. Comparison of pod damage and yield in chickpea cultivars under sprayed and nonsprayed conditions at ICRISAT Center, 1976-1977.

	Borer-damaged pods	Pods harvested	Yield
	(%)	(no)	(kg/ha)
JG-62 (desi):			
Sprayed	1.9	19096	1408
Not sprayed	8.2	20804	1324
L-550 (kabuli):			
Sprayed	2.5	12019	972
Not sprayed	10.6	8153	626

Insect Pest Damage

Most of the current chickpea entomology research is concerned with *Heliothis armigera* (Hub.) which is known to be the most damaging pest of this crop throughout Asia and Africa. In the 1976-1977 season at ICRISAT Center this insect was again the only really important pest on chickpea; during early growth of the plants the larvae were found feeding on the leaves and later they destroyed flowers and bored into the green pods.

In an attempt to quantify the yield loss caused by these insects on the kabuli and desi types, plots in which the plants were sprayed with endosulfan and from which the larger *H. armigera* larvae were removed by hand were compared with nontreated plots. The percentage of pods damaged, number of pods harvested, and seed yields are shown in Table 38.

Pest control gave a 55-percent increase in yield from the kabuli type; most of this clearly resulted from the increase in number of pods harvested. In the desi type there was no final reduction in pod-set in the nonsprayed plots and the small increase in yield from pest control was associated with the reduction in pod boring. These results confirm earlier observations that kabuli types are more heavily attacked by *H. armigera,* particularly during the flowering stage.

Pesticide Residue Analysis

DDT and endrin are the most commonly used insecticides for *H. armigera* control on chickpeas, but both of these chemicals have well-known disadvantages. We used endosulfan, which has fewer disadvantages, but its relatively high cost will discourage most farmers. Insecticide use during the flowering and green-pod stage introduces the possibility of toxic residues in the harvested seed. Samples of seed from endosulfan-treated plots were sent to the Tropical Products Institute in England for toxic-residue analysis. Endosulfan sulphate levels of up to 0.34 mg/kg of seed were detected; such a level may cause acceptance problems.

Screening for Susceptibility

It has been established that kabuli-type chickpeas are generally more susceptible to *H. armigera* attack than are the desi types and there is some evidence to suggest consistent differences in susceptibility within those types. This has encouraged intensification of the work in developing a screening program for "resistance" to *H. armigera.*

In an experiment to determine the effect of plot size in detecting susceptibility differences between cultivars, trials with plots of 4.8 and 20.0 m^2 were compared. Results of these trials, in which 13 cultivars were tested show the smaller plot size to be at least equal in efficiency in detecting differences, both in percentage of borer damage and in yield (Table 39). This was a welcome result, for it will permit additional replication without increased demand on seed or land. The susceptibility rankings of the cultivars were in good general agreement in the two trials; C-235 and L-345, both desi types, were the least susceptible while the kabuli types suffered most damage.

In a preliminary attempt to screen the germplasm collection for susceptibility, 8894 lines were sown in unreplicated small plots, with two check cultivars alternating after every 20 lines. *H. armigera* attacks were scored at the green-pod stage, and the percentage of damage was recorded when the pods were harvested. There was a fertility gradient across the field and *H. armigera* was more common in the better growing areas. Pod damage ranged from 0 to more than 50 percent in the check plots, so the individual records from the unreplicated germplasm lines can have little value, except perhaps in indicating the more obviously susceptible. Of the check plots, 28 percent of the C-235 (n = 219) and 19.5 percent of the BEG-482 (n = 221) were free from *H. armigera* damage, but only 11 percent of the 8 629 germplasm lines harvested had no damage. This is interpreted as an indication that C-235, and to a lesser extent BEG-482, are less susceptible than the majority of the germplasm cultivars. This was not unexpected, as both checks are well-adapted desi cultivars that have been grown generally without pesticide protection.

Although the natural infestation of *H. armigera* in the screening trials was augmented by the release of laboratory-bred moths, infes-

Table 39. Comparison of pod-borer damage and yields of 13 cultivars tested in small (4.8 m^2) and large (20.0 m^2) plots in randomized blocks with four replicates.

Cultivars	% Borer damage[a]		Yield	
	Small plot	Large plot	Small plot	Large plot
	(arcsin scale)		(g/m2)	(g/m2)
C-235	4.9	3.4	82.5	118.0
BR-70	4.4	10.6	47.7	68.8
L-345	3.0	2.6	60.4	74.6
L-2937	7.0	6.9	79.8	91.4
850-3/27	18.1	12.6	59.8	139.3
JGC-1	7.5	8.3	76.9	113.0
IC-6037	4.9	6.6	73.5	95.0
RS-11	6.1	7.1	81.0	84.2
NP-34	12.0	8.1	69.4	71.4
P-3090	18.2	16.6	68.5	55.2
NEC-143	13.3	11.0	44.4	79.1
Rabat	13.6	14.5	61.3	72.2
IC-682	9.5	9.3	77.3	86.0
S.E.±			9.33	15.35
c.v.(%)	21.5	22.0	27.4	34.8

[a]percent borer damage, bated on arcsin transformation.

tations were low and uneven. Most of the plants that were free from attack were probably escapes rather than "resistant." Improvements in screening techniques are of obvious priority. Attempts to screen plants in net houses were abortive, for the plants grew poorly and were etiolated. Techniques involving replication of small plots in fields of uniform fertility and the utility of inoculating individual plants with eggs or young larvae will be evaluated.

Another approach is to identify characters involved in reducing the susceptibility of plants. Chickpea exudes an acidic liquid throughout its growing period and it has been generally assumed that this exudate deters many insect pests, although one report suggests that it attracts *H. armigera*! Collaboration with the Centre for Overseas Pest Research in the United Kingdom has been established; chemists are analyzing the exudates. A preliminary analysis has shown that the exudate contains aconitic acid, which is known to be a feeding deterrent for some insects. It may be possible that these analyses will be useful in explaining, or even detecting, susceptibility differences conferred by the exudate composition.

Nutritional Quality

Estimation of Protein Content

Two rapid methods of estimating nitrogen content were compared with the micro-Kjeldahl (MKJ) method as a standard. With 98 pairs, the Technicon Auto Analyzer and dye-binding capacity methods gave results (r = 0.99 and 0.98, respectively) highly correlated with MKJ. The biuret method, developed for rapid determination of protein in cereals, gave slightly lower correlations and considerably higher standard errors than the other methods. We have concluded that either the Technicon Auto Analyzer or dye-binding capacity method is satisfactory.

The distribution of protein content (N x 6.25) in 6014 germplasm samples is shown in Figure 41. Content ranged from 14.3 to 30.9 percent.

Total Nitrogen and Nonprotein Nitrogen

Nitrogen in seed occurs in protein molecules and also in free amino-acids, other organic compounds, and in inorganic compounds. Estimation of protein content by multiplying nitrogen content by a particular factor is subject to error to the extent that nonprotein nitrogen is present in the sample. We analyzed 98 samples of chickpea and found the percentage of nonprotein nitrogen to range from 0.16 to 0.73. Expressed as percentage of total nitrogen, the nonprotein nitrogen ranged from 5.8 to 16.5. The percentage of nonprotein nitrogen in the sample tended to increase as protein increased (Fig 42). These preliminary results indicate the need for additional studies of seed nitrogen.

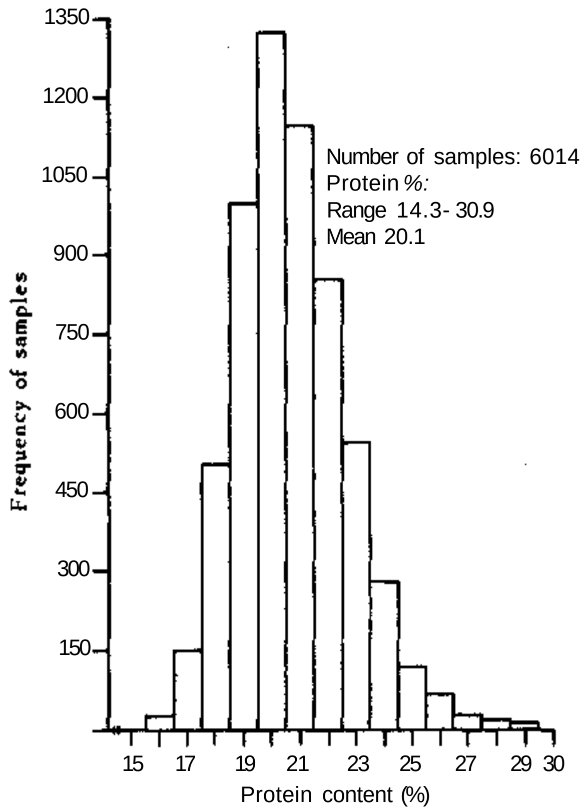


Figure 41. Range of protein content of 6014 chickpea germplasm samples.

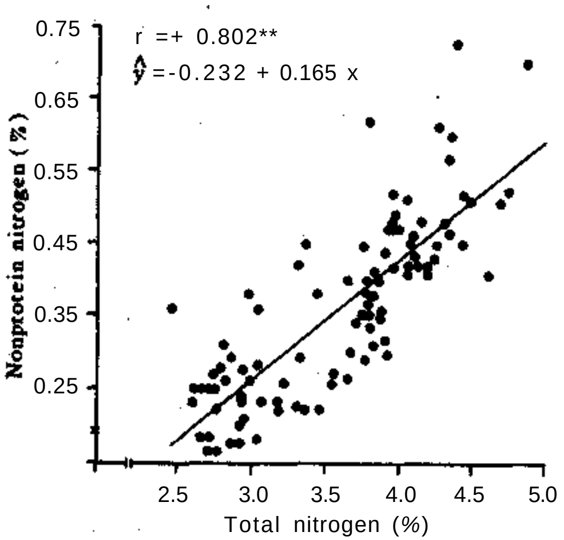


Figure 42. Relationship between total nitrogen and nonprotein nitrogen in chickpea.

limiting Amino Acids

As in most legumes, the sulfur-containing amino acids-methionine and cystine-are usually deficient in chickpea. We analyzed 30 samples with a range of nitrogen content from 2.40 to 4.85 percent for total sulfur. Although differences in sulfur percentage were small, there appeared to be an inverse relationship between percentage N and percentage S (Table 40). The sulfur/nitrogen ratio expressed as percent emphasizes the inverse trend.

Similar results were obtained when methionine content was determined by microbiological assay for 78 samples. There was a negative and significant correlation between percent protein and methionine as percent of protein (Fig 43). These results indicate that the additional protein formed in high-protein lines may consist of fractions which are low in the sulfur amino acids.

Composition of Some Chickpea Cultivars

Five kabuli and five desi.cultivars were analyzed for protein, starch, soluble sugars, fat, crude fiber, and ash content. Protein (N x 6.25) ranged from 19,4 to 24.4 percent, with no difference between desi and kabuli (Table 41). Starch content in desi cultivars (47.2 to 52.5%) was lower than in kabuli cultivars, which ranged from 56.1 to 59.7 percent. Other consistent differences included higher crude fiber content in desi cultivars than in kabuli cultivars, and lower fat content in desi cultivars.

International Cooperation

Furnishing of superior breeding material to local breeding programs is the most hopeful way of making progress in increasing chickpea yields. In the past year we distributed screening nurseries of 100 early and 100 late-maturing advanced lines from our breeding program. Results have been received on the early group from 11 locations and on the late group from 13 locations, all in India. Results from nine other countries were not received in time for analysis.

Table 40. Total sulfur and nitrogen in 30 chickpea germplasm lines.

	N	S	S/N
	(%)		
High N lines (12)	3.85-4.85	0.17-0.21	3.7-5.0
Medium N lines (8)	3.05-3.84	0.17-0.23	4.5-6.9
Low N lines (10)	2.40-3.04	0.18-0.24	6.5-8.8

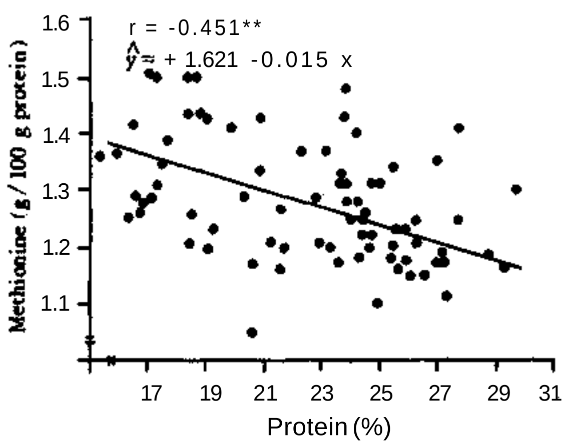


Figure 43. Relationship between protein and methionine contents in chickpea.

Table 41. Chemical composition of some chickpea cultivars, expressed on a moisture-free basis.

Cultivar and Source	Protein	Starch	Soluble sugars	Fat	Crude fiber	Ash	Total
	(%)						
Desi types							
JG-62 (India)	22.0	47.2	4.1	3.8	10.1	3.1	90.3
Pyroz (Iran)	19.7	52.5	5.6	3.5	7.1	3.2	91.4
NEC-240 (USSR)	22.3	47.5	4.0	3.8	7.9	3.1	88.6
NEC-1639 (Pakistan)	24.0	47.5	4.2	4.0	10.0	3.4	93.1
USA-613 (USA)	20.9	48.0	4.8	3.8	7.4	3.2	88.1
Kabuli types							
L-550 (India)	19.4	59.7	4.3	5.7	3.2	3.1	95.4
NEC-34 (Iraq)	21.0	57.9	5.5	5.3	6.0	3.1	98.8
Lebanese Local (Lebanon)	21.5	57.6	5.2	5.0	5.6	3.1	98.0
NEC-10 (Jordan)	21.4	58.6	4.6	5.3	5.1	3.3	98.3
NEC-143 (Sudan)	24.4	56.1	5.3	4.8	5.6	3.1	99.3

We considered each location as a replicate, and analyzed the results received. One line in the early group and five lines in the late group yielded significantly higher than the check when averaged over all locations. Lines with high average yields from each set will be offered for testing in the all-India coordinated trials. Lines performing best at some of the locations are being further tested by the local breeders.

Other sets of material distributed include the observation nursery containing cultivars for use as parents in crossing, yield trials of desi and kabuli cultivars, and disease observation nurseries. Results of the trials and disease observations are summarized and distributed to cooperators.

Breeding populations supplied on request are usually sent in the F_3 generation for local selection. A summary of all materials supplied to cooperators over the past two years is listed in Table 42.

Communication is supplemented by exchange of visits with cooperators. We have visited 15 of the 28 countries with whom we are cooperating, and have had scientists from 13 of the countries visit ICRISAT.

Two trainees from Ethiopia and one from Sudan completed a course in chickpea breeding.

Looking Ahead in Chickpea Improvement

A catalog of chickpea germplasm will be published soon. Filling of gaps in the collection will continue, with high priority areas being the Bundelkhand region, Rajasthan, and Madhya Pradesh in India, as well as Ethiopia, Afghanistan, Pakistan, Bangladesh, Iran, and Turkey. Work will be intensified on evaluation and utilization of wild *Cicer* species.

Additional emphasis will be given to breeding more productive plant types, and responsiveness to fertilizer plus irrigation will be investigated in late-planted material at Hissar.

Field screening for *Ascochyta* blight will be initiated to supplement laboratory tests, and field-screening techniques for resistance to stunt will be investigated.

Selected germplasm lines will be resurveyed at ICRISAT Center and Hissar to identify those which form large numbers of active nodules. A

Table 42. Test and breeding material furnished to cooperators for the 1975-1976 and 1976-1977 seasons.

Material	Countries	Locations	Sets
	(no)	(no)	(no)
Yield trials	28	54	176
Screening nurseries	24	63	152
F_3 bulk populations	18	28	87
Disease nurseries	7	16	16

breeding program to increase nitrogen fixation will involve the best lines as parents. We will attempt to elucidate the factors causing the rapid decline in nitrogenase activity during pod-fill at ICRISAT Center.

Highly effective *Rhizobium* strains will be tested as inoculants under field conditions. We plan to measure the amount of nitrogen fixed by the chickpea crop and to determine the residual effect on a following cereal crop.

Techniques for screening breeding material for pod-borer susceptibility will be investigated.

More work will be carried out to identify drought-tolerant cultivars and to develop reliable field-screening techniques for this character. Methods for identifying salt-tolerant cultivars, using chambers containing artificially salinized soil, and for screening cultivars for the ability to germinate under conditions of limited soil moisture will be investigated. Work will be carried out at Hissar to compare growth and development with and without irrigation before sowing.

At ICRISAT Center, the influence of heat stress and moisture stress on source-sink relationships and yield will be investigated in experiments involving early and late plantings with and without irrigation. Further efforts will be made to develop a simple field method for measuring plasticity differences in cultivars, as reflected by their response to different population-densities.

Characterization of the protein fractions in chickpea will be done, and rapid testing techniques for the desirable fractions will be investigated.

International cooperative activity will be intensified, both in the area of chickpea improvement and in expanding the training component of the program.

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 2500 kg/ha and in some areas will often be 5000 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 postrainy and hot dry seasons in order *to* facilitate the breeding program.

GROUNDNUT

Groundnut

The groundnut improvement program commenced in April 1976 with research in breeding, microbiology, pathology and virology, and germplasm. In November a mycologist was recruited and work started on screening techniques for leafspot and rust fungi. In 1977 an entomologist was recruited, and we anticipate that by early 1978 physiological and cytogenetical work will commence. Although much of the year has been necessarily spent in organizing and obtaining equipment, considerable progress has been made - particularly in virology and obtaining germplasm, in spite of strict quarantine restrictions. Much of our disease-resistant material has now been released from quarantine, and we expect an increase in the tempo of the breeding program.

ICRISAT's groundnut program aims to increase the low yields (around 800 kg/ha or less) of groundnuts obtained by small-scale farmers in the SAT, mainly by incorporating resistance to the prevalent diseases, such as leafspots and rust. Physiology research will concentrate on identifying sources of drought tolerance, because unreliable rainfall patterns also contribute to low yields.

Germplasm

The International Board for Plant Genetic Resources (IBPGR) has nominated ICRISAT as a major germplasm center for *Arachis.* Priority has been given to assembling the extensive collections of *Arachis hypogaea* already existing at research stations in India. Thanks to the cooperation of Indian institutions, we feel this task has been largely accomplished during the past year. Details of these collections are given in Table 43.

There will be many duplicates in this collection and in rainy season 1977 the total collection will be planted out according to botanical type to help identify and eliminate duplicates. Systematic controls to facilitate yield evaluation will also be planted. Many of the accessions from some centers do not have sufficient background data on their pedigree or origin. The accession registers at the National Bureau of Plant Genetic Resources, New Delhi, were therefore searched and all the information on groundnut imports from 1947 to 1976 were extracted and published. This will assist in relating original import numbers (EC numbers) to local germplasm collections. Collection of local material has also

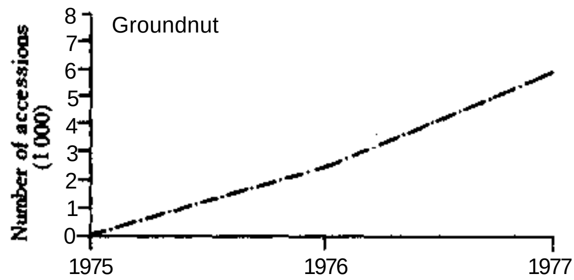


Figure 44. Groundnut germplasm accessions at ICRISAT Center.

Table 43. Accessions of *A. hypogaea* from research centers in India.

Collection No.	Source	Accessions
1	Kadiri	1097
2	Karimnagar	273
3	Ranchi	223
4	Jalgaon	245
5	Pantnagar	11
6	Rajasthan	58
7	Tindivanam (AICORPO)	463
8	Junagadh	1159
9	Tindivanam (OES)	29
10	Coimbatore	29
11	Ludhiana	496
12	Akola	110
13	Amravati	160
14	Pollachi	297
15	Bombay (BARC)	9
16	Mahabaleshwar	4

been undertaken, particularly in those areas where improved cultivars have not been released.

Import of exotic cultivars from major germplasm centers abroad has been necessarily slow, due to the strict plant quarantine measures to prevent the spread of new seed-borne pathogens into India. At present, imported seeds are planted in a screenhouse at the Rajendranagar quarantine station and inspected regularly for disease symptoms. After approximately 6 weeks, young healthy plants are released to us for transplanting in the postquarantine area at ICRISAT Center. Fortnightly quarantine inspections are carried out until the plants mature, and their produce is then released to us. Even so, during the year approximately 750 cultivars have been released to us and a further 90 accessions are in the postentry quarantine block. A further 900 exotic cultivars are awaiting primary quarantine clearance. Among the important material now released are two cultivars with rust resistance (a further 14 rust-resistant lines are in the postentry quarantine area), two breeding lines with resistance to *Aspergillus flavus,* material resistant to leafspots, and an accession with extreme earliness. We have managed to have this breeding material released by asking for priority processing in relation to normal germplasm resources. Several wild *Arachis* species, including those with disease resistance, have also been received and established.

During rainy season 1976 some 2 000 cultivars from Indian research centers and 331 exotic lines were planted and evaluated. Due to the erratic rainy season and abundance of fungal and viral diseases, the collection was evaluated for additional sources of resistance to rust and leafspot-but without success. A dry period during August and September allowed us to score for drought tolerance. Thrips counts were also taken on all cultivars; 21 lines with little damage caused by this pest (and virus vector) were identified for further study. In the 1976-1977 postrainy season 178 new exotic cultivars were planted in addition to the 331 harvested from the rainy season crop. The yield from this crop was higher than had been obtained previously and the collection was also screened for reaction to bud necrosis virus.

Groundnut germplasm was supplied to research workers in India and several other nations (Table 44).

Breeding

The main breeding programs are aimed at the incorporation of disease resistance into high-yielding commercially accepted cultivars. As we were totally dependent on the importation of disease-resistant parents, we had to await quarantine clearance of such material before we could proceed with our main breeding objectives. In the interim a team of operators was trained in emasculation and pollination techniques, using germplasm from local sources. Plants were raised initially in pots kept in the open; despite plant protection measures, bud necrosis virus seriously affected the rate of successful pollinations. A new set of parents was raised in the new screenhouse

Table 44. Groundnut germplasm lines supplied to research agencies in India and other nations during 1976-1577.

Institution	Location	Entries
Agricultural Research Institute	Karimnagar, A.P. India	2
Department of Primary Industries	Brisbane, Australia	36
Agricultural Research Centre	Semongok, Malaysia	36
Agricultural Research Station	Maha Illuppallama, Sri Lanka	46
University of West Indies	St. Augustine, Trinidad	25

Figure 45. Field hybridization techniques with groundnut.

completed in December 1976, and with humidifiers to provide high humidity at the time of pollination, we achieved a success rate of 23 percent - which is still less than expected for groundnuts. Although the constraints have not been fully identified, recent figures indicate a further rise in our percentage of successful pollination. As we can achieve large numbers of pollinations, we have planted over 300 seeds from these initial crosses together with their parents to eliminate selfs from the F_1 plants. Many Indian centers do their crosses on field-grown plants so we have planted cultivars on wide-spaced ridges to compare field and screenhouse methods. These cultivars represent different botanical varieties having high yield and other desirable characters.

Breeding for resistance to the leafspot fungi caused by *Cercospora arachidicola* and *Cercosporidium personation* is under way in collaboration with scientists at Reading University, UK, and the British Ministry of Overseas Development. At Reading triploid hybrids were produced between the tetraploid groundnut, *Arachis hypogaea,* and two wild diploids, *A. chacoense* and *A. cardenasii,* which are highly resistant to C. *arachidicola* and *C. personatum* respectively. Another diploid, *A.* sp. HLK 10, reputedly resistant to both fungi, was also crossed with *A. hypogaea.* These sterile triploids were treated with colchicine at Reading to produce fertile hexaploids. Cuttings of these hexaploids, plus some of the original triploids, were sent to ICRISAT and after rooting in a quarantine screenhouse they were held planted. A high natural infection of *C. personatum* was produced by interplanting the hybrids with highly susceptible cultivars and spreading infected leaves around the plants. All the plants were scored for reaction to leafspots and other diseases, as well as for flower and pod production. Plants appearing to be highly resistant were selected for further screening and backcrossing to the cultivated groundnut. The pod production on the hexaploids varied from zero to more than a hundred pods per plant.

We have so far harvested approximately 100 seeds from crosses involving the two rust-resistant cultivars, PI 259747 and PI 298115, and high-yielding but rust-susceptible parents. Fourteen additional resistant F_3 lines (FESR 1-14) derived from a natural cross between PI 298115 and an unknown pollen donor are presently being assessed in the postentry quarantine area. As these lines are still segregating, each plant will be tested for rust resistance, yield, and quality characters.

Introductions released from quarantine and currently being used in other hybridization programs include breeding lines with resistance to *Aspergillus flavus* and others with earliness.

As conventional groundnut breeding programs are slow, we are investigating methods of reducing the time needed to advance segregating populations. Ethephon, an ethylene-producing compound formulated as a dust, is currently being used to break seed dormancy in freshly harvested normally dormant cultivars. In the laboratory more than 90 percent of the freshly harvested dormant seed germinated within 24 hours of harvest. A field trial in postrainy season 1976 with freshly harvested seed from the previous rainy season gave similar results (Fig 46).

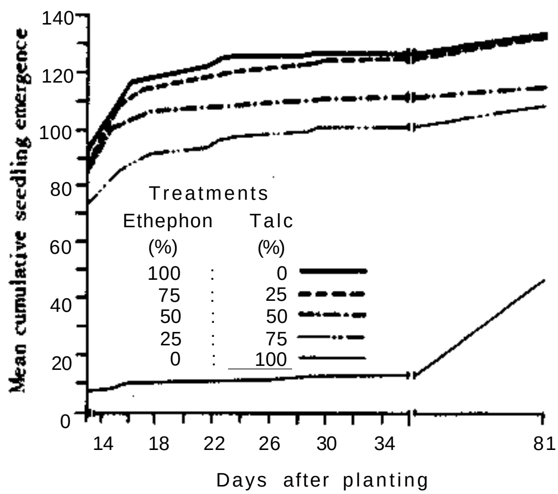


Figure 46. Seedling emergence in Ethephon-treated dormant groundnut (postrainy season 1976).

We have developed a close working relationship with AICORPO, the All-India Coordinated Research Project on Oilseeds. We planted four national trials under nonirrigated rainy season conditions at ICRISAT Center in July 1976 and replanted two of them on our own initiative in December 1976 under full irrigation for comparison purposes. The results (Table 45) show that rainy season yields, shelling percentages, and kernel weight this year were much lower than those of the postrainy season due to leafspots, rust, and erratic rainfall in August and September 1976.

Table 45. Performance of cultivars in cooperative national groundnut trials [AICORPO trial CVT (Bunch)] at ICRISAT Center during rainy and postrainy seasons, 1976.

Cultivars	Mean time to 50% flowering		Mean yield[b]		Shelling percentage		100-kernel weight	
	Rainy[a]	Postrainy[a]	Rainy	Postrainy	Rainy	Postrainy	Rainy	Postrainy
	(days)	(days)	(kg/ha)	(kg/ha)	(%)	(%)	(g)	(g)
Robut 33-1	29.6	40.8	1711	3715	55.0	79.2	32.18	54.58
X14-4-B-19-13	26.3	38.8	1017	3173	60.0	72.3	32.62	42.44
Ah-8189	27.0	38.8	1004	2448	62.5	77.7	22.02	31.82
Argentine[c]	27.5	38.3	962	3025	64.5	77.3	22.31	40.54
Pol-2	27.3	39.5	933	3063	64.0	74.2	27.30	34.42
X9-2-B-25-B	26.5	38.0	904	3440	64.0	74.2	25.48	43.86
X14-4-3-8-B	26.8	38.0	895	2336	59.0	70.8	27.65	43.54
FSB-7-2	27.0	38.0	895	3 333	62.0	78.6	25.75	36.72
OG-69-6-1	26.5	38.3	863	3490	66.0	74.2	26.52	32.22
MGS-7	26.8	38.5	855	2992	64.0	76.8	24.24	32.86
OG-71-3	26.5	38.0	838	2817	58.0	74.7	26.17	36.33
OG-1-13-3	26.8	39.3	835	3 344	64.0	77.6	27.83	44.28
NG-268	27.3	39.0	804	3317	52.0	78.7	23.54	29.82
MGS-8	27.0	38.5	802	3525	68.5	76.3	25.76	42.75
Ah-8254	27.5	38.3	754	3 242	60.0	78.3	22.45	40.35
99-5	26.5	39.0	738	3512	58.0	80.0	27.34	41.66
JH-89	27.0	39.0	736	2988	68.0	74.2	24.95	45.86
OG-3-24	26.8	37.8	723	3173	70.0	76.8	24.24	42.57
148-7-4-3-12-B	26.0	38.5	715	3312	65.0	75.8	23.90	36.68
MGS-9	26.8	39.0	698	3 709	62.0	77.8	22.32	30.26
FSB-7-5	27.3	39.0	684	2454	58.0	75.3	22.30	46.29
Ah-8253	27.0	38.5	669	2769	66.0	75.8	20.10	34.22
Tifspan[c]	27.0	38.0	479	2781	60.0	77.6	21.16	35.61
L.S.D. (0.05)			191	814				
C.V.(%)			16.77	18.55				

[a]In rainy season trials, cultivars reached maturity in 102 days; in postrainy season trials, 160 days were required.
[b]Mean yield over four replications.
[c]Argentine and Tifspan were controls.

Pathology

Bud necrosis virus (BNV) was again observed in field plantings at ICRISAT Center in August 1976, some 40 to 50 days after planting, and the disease reached serious proportions. Surveys carried out in Andhra Pradesh showed that between 30 and 70 percent of the plants in some fields were infected with the virus. This disease has been reported from all groundnut-growing areas of India. The first symptoms on newly opened leaflets vary from small indistinct chlorotic rings to larger concentric rings interspersed with green islands. Later necrotic streaks appear on the petioles and spread down the stems. Often the terminal bud becomes necrotic and dies, leading to proliferation of axillary shoots. The plants become stunted and later-formed leaves are smaller in size and show varied symptoms such as mottling, vein clearing, cupping, and curling; they sometimes become filiform. Early infected plants may die; even in less severe cases yield is greatly reduced. If kernels are formed they are small and wrinkled with dark lesions on the testa.

The virus is easily transmitted mechanically as long as an antioxidant such as 2-mercaptoethanol is included in the phosphate buffer at pH 7.0. Several other antioxidants were tested but 2-mercaptoethanol was superior in that more local lesions were produced on the cowpea assay host (*Vigna unguiculata* cv C152). Using infected sap with the buffer and 2-mercaptoethanol, some 16 genera of plants showed symptoms when mechanically inoculated.

Physical properties of the virus were investigated using classical techniques and cowpea as an assay host. The thermal inactivation point (TIP) was calculated to be between 45 to 50 C and the dilution end point (DEP) was between 10^{-2} and 10^{-3}. Healthy and freshly infected leaf tissues were fixed in paraformaldehyde and 50 % gluteraldehyde and sent for electronmicroscopy to the United States, Australia, and Japan. Virus particles were not observed. Various insects were tested as possible vectors; of these only thrips (tentatively identified as *Scirtothrips dorsalis)* successfully transmitted the virus.

Based on all the evidence available, it became apparent that the bud necrosis virus closely resembled tomato spotted wilt virus (TSWV) which has been reported only occasionally on groundnuts in USA, South America, South Africa, and Australia. Therefore, TSWV antiserum was obtained from sources in three different countries; peanut mottle virus (PMV) and peanut stunt virus (PSV) antisera were also obtained from USA. Sheep red blood cells were coated with antisera of TSWV, PMV, and PSV. Various dilutions of healthy and virus-infected groundnut leaves were reacted against tanned blood cells coated with different sera. The cells coated with TSWV antibody gave titers up to 1/400 for healthy and 1/3200 for infected leaf extracts. PMV- and PSV-coated cells did not react with either healthy or bud necrosis-infected

Figure 47. Effect of virus on groundnut seed quality in petri dishes.

leaf extract. The titers obtained with infected leaf extracts were eightfold those of healthy leaves, indicating that TSWV antigens were present in bud necrosis-infected leaves. Confirmatory evidence was obtained from latex agglutination tests. Latex particles (0.46 μ in diameter) coated with TSWV antiserum were reacted with different dilutions of healthy and infected leaf extracts. Healthy leaf extracts gave a titer of 1/100 compared with 1/400 in extracts from infected plants, again suggesting the presence of TSWV antigens in bud necrosis-infected plants.

During rainy season 1976, 331 cultivars from USA were scored in the field for the presence of BNV. No accessions were found to be virus-free, and the incidence varied from 30 to 80 percent. Further field screening was carried out on the 1976-1977 postrainy season crop but only four germplasm lines (Acc. Nos. 2188, 2575, 2372, and 2932) showed late infection, which may indicate some field tolerance to the virus. One row of Acc. No. 1107, however, remained virus-free. All the field-scored lines and the unaffected row of Acc. No. 1107 were then inoculated in the laboratory, using the mechanical method perfected earlier. Apart from one plant of Acc. No. 2372, all accessions developed bud necrosis when mechanically inoculated. Even when grafted with infected scions, the single plant of Acc. No. 2372 apparently remained virus-free; the control plants developed typical symptoms. This plant has now been multiplied by vegetative cuttings and will be retested as a possible source of resistance to the virus.

Several other viruses collected from surveys in India are also under investigation. One virus caused stunting and produced oval-shaped chlorotic spots on the leaves; the spots tended to fade as the plant aged, leaving mild mottle symptoms. There was no necrosis or proliferation of axillary shoots. When infected scions were grafted onto healthy plants, typical symptoms were produced in 2 to 4 weeks. This disease has been tentatively named chlorotic spot virus (CSV). Mechanical transmission of the virus could be achieved by using 0.05 M potassium phosphate buffer at pH 7.0 with added 0.02 M 2-mercaptoethanol. Good assay hosts were French bean (*Phaseolus vulgaris)* and cowpeas. *Nicotiana rustica* was also used extensively for laboratory tests, as large amounts of the virus could easily be recovered from it. Some physical properties of the virus have been determined. The virus was infective after 72 hours' exposure to room temperature (25-30°C) and also when held at 4°C. The thermal inactivation point (TIP) of the virus was determined to be around 80°C. Concentration of the virus was achieved by centrifugation at 30 000 rpm after extraction in phosphate buffer and clarification. Further purification was achieved by two cycles of sucrose gradient centrifugation at high speeds. Several different zones were detected and the zone containing virus particles was detected by performing infectivity assays on French beans and cowpeas. Using the purified virus, we are now in the process of producing CSV antiserum. Fixed leaves were sent to Australia for electronmicroscopy and thin sections showed the presence of large inclusion bodies normally found in "caulimo virus" infections. Copper mesh grids coated with Formvar membranes were supplied to us from Japan and our purified virus was placed on the grids before being fixed and stained. Leaf dip samples were also prepared. Electronmicroscopy was carried out in Japan and icosahedral virus particles of 40 to 50 nm in diameter were clearly discernible. Further work is in progress to determine the precise diameter of the particles. Results indicate that this virus is extremely stable and has a low sedimentation coefficient between 100 and 200 Svedberg units. It is thought that CSV may belong to the group of viruses containing DNA.

Another disease has been tentatively named "vein-banding disease" (VB). During surveys in Andhra Pradesh, the incidence varied from 1 to 4 percent in most fields, but on a few farms up to 10 percent of the plants were infected. Diseased plants have also been seen at ICRISAT Center. Early symptoms show vein-banding on newly emerged leaflets giving an. oak-leaf pattern. Leaf size is considerably smaller and the tips flex downwards. Internode length is reduced and this is followed by shoot proliferation, profuse flowering, and peg production. Although pegs are numerous, only a few develop into mature pods and the kernel size is considerably smaller. Typical symptoms were observed in 3 to 4 weeks on healthy plants grafted with diseased scions. Using the buffer and antioxidant described earlier, mechanical transmission was made to several host plants. *Chenopodium quinoa* showed chlorotic local lesions and the infection became systemic. On soya *(Glycine max* cv. Bragg), systemic mosaic mottling occurred. When mechanically transmitted to groundnuts, the vein-banding symptom was produced but no axillary shoot proliferation, stunting, profuse flowering, or peg formation occurred and the subsequently formed leaflets were chlorotic and malformed. Mechanical transmission from C. *quinoa* and *G. max* back to groundnuts also produced these atypical symptoms. Small quantities of seed from infected seed remained healthy when germinated. The results at present indicate

Figure 48. A rust-resistant groundnut cultivar growing at ICRISA T Center.

that more than one agent may be involved in this disease. One component is a sap-transmissible virus. The profuse flowering, pegging, and axillary shoot formation are similar to symptoms produced by mycoplasma or *Rickettsia*-like organisms.

Priority has been given to the two most important worldwide foliage fungi of groundnuts - rust (*Puccinia arachidis*) and leafspots (*Cercospora arachidicola* and *Cercosporidiumpersonatum*). Rust has spread at an alarming rate over the last few years to all the major groundnut-producing areas. However, little is known about its biology, the presence or absence of physiological races, or its methods of survival. Infected leaf debris collected in rainy season 1976 and exposed to natural weather conditions was assessed at weekly intervals for viability of the uredospores. At the time of collection, germination was in the region of 70 percent, after one week this had fallen to 30 percent and in a further week to 1 percent; after that, uredospores did not germinate. In the 1976-1977 postrainy season, the results were similar. Only the uredial stage of the fungus was found, despite intensive searches for the telial stage which has been recorded in South America. None of the 37 weed plants and 11 cultivated plants inoculated with rust produced symptoms.

To assist the breeding program, a reliable screening technique for detecting rust resistance is urgently required. Plants 30 days old were inoculated with uredospore suspensions and kept at 100 percent relative humidity at 25 to 30°C for 48 hours before being transferred to ambient conditions. Abundant uredosori were produced in 8 to 10 days. This technique will be standardized to provide a high inoculum source for field testing populations produced by the breeders in their rust-resistance breeding program.

A detached-leaf technique for detecting sources of resistance is also being investigated. This technique will have the advantage of testing, with a known intensity of inoculum under controlled conditions, large amounts of material in a small area. During some initial tests, leaves which were detached 5 days after unfolding were found to be the most suitable. After detachment, the petioles were placed in various culture solutions with or without additives. The most suitable media for keeping the leaves in good condition were found to be either Hoagland or Shrive and Robbins solutions with added kinetin at 20 ppm or benzimidazole at 20 to 60 ppm. The detached leaves were sprayed with uredospore suspensions and incubated under 100 percent relative humidity and temperatures of 25 to 30°C for 2 days. The leaves were then maintained at 70 to 80 percent relative humidity and cool temperatures. Sori began to develop 8 days after inoculation; they soon darkened and enlarged before rupturing and releasing masses of uredospores. Comparisons of the detached-leaf technique with whole-plant inoculation show that disease development is similar in either case.

The leafspot fungi cause worldwide reductions in groundnut yields each year. In India and parts of Africa, *C. personatum* is the dominant species; in USA and other parts of Africa, *C. arachidicola* is more important. We need to develop reliable screening techniques to assist breeders in their selection of resistant segregates. Although it has been reported that both fungi can be cultured on artificial media to produce conidiospores, spore production on the recommended media was not sufficient for our purposes. Other media, which had been recommended for different species of *Cercospora,* were tried but success was limited. Recently we have gained much more satisfactory results with malt agar supplemented with inocitol and thiamine hydrochloride; further investigations are being carried out with this medium. Conidial suspensions from infected leaves have given lesions on young plants in 13 days after an initial 72 hours of incubation at high humidities followed by transfer of the plants to ambient conditions.

Cultures of *Aspergillus flavus* are being isolated and maintained for use when the breeding program for resistance to this important fungus gets under way in the near future.

Two disease surveys were carried out in Andhra Pradesh. At most sites leafspots and rusts were the major pathogens. Other important fungi included *Aspergillus flavus, A. niger, Leptosphaerulina arachidicola, Sclerotium rolfsii, Rhizoctonia bataticola,* and *Fusarium* spp. At ICRISAT Center *Rhizopus* spp. was causing seed rots in stored kernels as well as in the field, and a *Pythium* sp. caused seedling damage in the screenhouse. Cultures of many of these fungi are being maintained for further study.

Microbiology

Unlike many grain legumes, groundnuts continue to form numerous active nodules well into the grain maturity stage. In rainy season 1976 cultivar Kadiri 71-1 had formed an average of 70 nodules/plant 28 days from sowing, with approximately half of them on the primary root. By 90 days there were 125 nodules per plant and this increased to 190 per plant by 111 days. Although the first-formed nodules senesced by 70 days, nitrogenase activity as measured by acetylene reduction assay continued until just before harvest.

Nodulation and nitrogen fixation was apparently little affected by seed treatment with ethephon, or by application of herbicides and fungicides.

A significant diurnal periodicity in nitrogenase activity was noted in cv Kadiri 71-1 when examined 81 days after sowing in postrainy season 1976-1977. Activity increased rapidly until 1400 hrs and then declined until dawn (Fig 49). After-dawn activity again increased rapidly, suggesting a close link between nitrogenase activity and photosynthesis. The rapid decline after 1400 hrs may be related to the cloud cover which developed by 1430 or to reduced photosynthetic activity because of previous stomatal closure. This periodicity means that for valid comparisons of nitrogenase activities under different treatments, the assays would need to be done on the same day and at the same time of day.

In the postrainy season the effect of drought stress on nodulation and growth of cv Kadiri 71-1 was determined by withholding every alternate irrigation to some plots. Nitrogenase activity per plant reached a maximum at 54 days after sowing, just before the first stress was applied. By 66 days, activity had declined to 54 μ moles C_2H_4/plant per hour for control plants irrigated 8 days previously and to 16 μ moles/plant per hour for plants stressed for 20 days. Upon irrigation at 68 days, activity was increased to 87 μ moles/plant per hour in both treatments, and this pattern was repeated during subsequent stress and irrigation periods. Stressed plants produced less top and root growth and the yield of 1 481 kg/ha was only half that of control plants receiving regular irrigations.

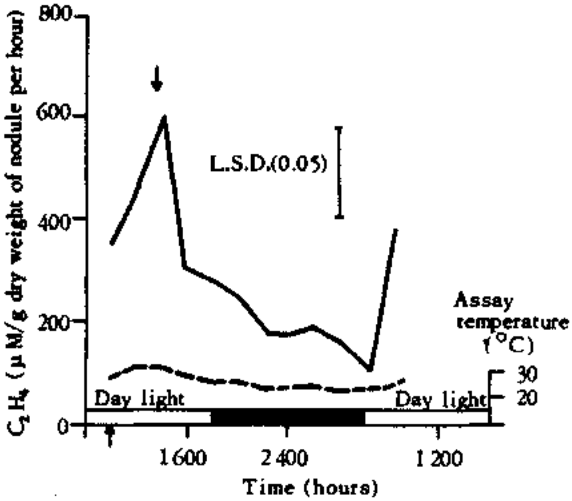


Figure 49. Nitrogenase activity (μM C_2H_4/g dry weight of nodule per hour) in groundnut cultivar Kadiri 71-1, 81 days after planting, ICRISAT Center, postrainy season 1976.

There were significant differences in nodulation between the more than 400 germplasm lines screened during the rainy and the postrainy seasons. A few cultivars had much better than average nodulation and a few were poorly nodulated. During field surveys, nodulation was noted to vary a great deal between locations and soil types.

Looking Ahead in Groundnut Improvement

In the germplasm program we intend to develop Jinks with the IBPGR to enable us to prepare a set of descriptors and an acceptable international groundnut classification system based on taxonomic and agronomic characters. We expect to have available shortly large quantities of germplasm for cooperators; and we will be increasing our own collection by additions from abroad. Germplasm catalogs will be produced as soon as possible.

As far as breeding goes, we hope to produce through a large-scale crossing program high-yielding material with stable resistance to the major pathogens. Other breeding objectives are to incorporate earliness and dormancy with high yield potential.

The virologists will continue their work on characterizing and purifying the viruses under current investigation. They will develop international and regional arrangements for the survey of all groundnut-growing areas to precisely identify important viruses. Rapid germplasm-screening techniques will be perfected to assist breeding programs.

Efficient fungal-screening techniques for large scale field testing of breeding populations with resistance to leafspots and rust will receive priority in the immediate future. For the major foliage fungi, we hope to set up testing centers in a number of countries to monitor stability of resistance and to detect the development of physiological races. We hope to develop rapid methods of laboratory screening for the detection of lines with resistance to invasion by toxin-producing fungal strains, such as yellow mold (*Aspergillus flavus*).

Planning for the entomology program is now complete; it will get under way in late 1977. Objectives of the program include survey of the harmful and beneficial arthropods of groundnuts, study of the vectors of diseases, and assessment of the role of insects as pollinators in groundnuts.

In microbiology, differences between lines in nodulation and the interaction with *Rhizobium* strain will be characterized to see if nitrogen fixation increases with nodule number. Selected lines with enhanced nitrogen-fixing activity will be incorporated in a breeding program for increased yield of total plant dry matter and kernels. We also plan to examine the relationship between carbohydrate storage and movement within the plant and nitrogen fixation, again in order to select plants for use in a breeding program for increased nitrogen fixation and hopefully yield. The effect of drought stress on nitrogen fixation will be examined in more detail to characterize differences between lines at various growth stages. We plan to survey the major groundnut-growing areas in order to determine patterns of nodulation in groundnuts growing in the field.

By 1978, we hope to initiate cytogenetics and physiology programs. In the physiology project, the major study will be on locating sources of drought resistance in groundnuts.

FARMING SYSTEMS

The goals of ICRISAT from the beginning have embraced development of improved systems of farming. In genera], 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 Systems research programs can be presented in three statements-

- to aid in generating economically viable labor-intensive production technology winch makes a better use of the productive potential of resources while at the same time conserving and improving resources.
- to assist in development of technology for improving land and water management and resource 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 postrainy 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 tins will also require collection and storage of runoff and the efficient utilization of stored water and groundwater.

FARMING SYSTEMS

Farming Systems

Rainfed agriculture has failed to provide even the minimum food requirements for rapidly increasing populations in many developing countries of the semi-arid tropics (SAT). Although the reasons are many, the 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 undependable rainfall conditions. The severity is amplified by generally high evaporative demands and, in many areas, by shallow soils with limited water-holding capacity.

The situation is intensified because farmers have increased the cropping areas and livestock numbers in an attempt to provide the food required for expanding populations. Vast areas have been over-cropped and over-grazed, resulting in serious soil degradation. The decreasing production potential has intensified the quest for additional land. To break this vicious circle, more stable forms of land use-forms which preserve, maintain, and better utilize the productive capacity of available resources-are urgently needed.

The Farming Systems research program at ICRISAT Center is striving to do research which will make a contribution to an improved economic status and quality of life for small farmers with limited means who comprise the majority of the farming population of the SAT. The larger farmers, who occupy most of the land and employ much of the landless labor are also expected to benefit. By investigating all facets of resource inventory, development, management, and utilization and all factors involving crop production in a systems approach, scientists at ICRISAT expect to develop basic principles, approaches, and methodologies which can be readily adapted as alternative, economically viable farming systems in the SAT.

To meet its objectives, the Farming Systems research program is involved in the following activities:

1) To assemble and interpret existing baseline data in several areas of science relevant to agriculture in the SAT.

2) To assemble and communicate to cooperators basic and applied research results related to farming in the SAT.

3) To conduct basic and supportive research in agroclimatology, hydrology, soil physics, soil fertility and chemistry, farm implements, land and water management, agronomy, and cropping systems.

4) To perform simulation or systems-analytic studies based on climate, soil, and socioeconomic information, so as to predict potentials of new crops, cropping systems, and soil-, water-, and crop-management practices.

5) To organize international cooperative trials to rapidly gain information about the performance of a practice, technique, or approach over time at the same location and/or across locations.

6) To provide support and expertise for ICRISAT training programs which are concerned with farming systems.

7) To perform research on resource management, crop production, and resource conservation at ICRISAT Center and selected bench-mark locations.

Results of the past year's work are reported in the following major categories:

Research in subprogram areas
Watershed-based resource utilization research
Cooperative research with national programs

Research in Subprograms

Much of the research in the various subprograms is carried out on a wide spectrum of activities or experiments within the particular disciplines involved. These range from basic studies to applied studies which may find immediate application for increased production. However, each subprogram has a problem-oriented focus towards the stated ICRISAT objective: "To develop farming systems which will help to increase and stabilize agricultural production through better use of natural and human resources in the seasonally dry semi-arid tropics."

"Watershed-based resource utilization research" is conducted on watershed units on Alfisols and Vertisols. It is the operational testing ground for principles and leads developed in the various subprograms where rainfall-use efficiency and economics of alternative farming systems are investigated. Thus scientists in all subprograms in the Farming Systems research program, as well as economists, plant breeders, entomologists, physiologists, pathologists, and microbiologists, are involved in facets of the operational-scale systems research in the watershed units.

Agroclimatology

Crop production and crop suitability, for a particular cultivar at a particular location, are determined primarily by interaction of moisture, temperature, and radiation. In planning for agricultural development and transfer of agricultural technology, climatic data is essential. The Agroclimatology subprogram is therefore primarily concerned with the collection, assembly, and interpretation of climatic data for ICRISAT Center and other locations of concern in the SAT. The quantification of the moisture environment for crop growth is also being attempted. A sample analysis for the Hyderabad area of India was reported in ICRISAT's 1975—1976 Annual Report.

The distinctive characteristics of the semi-arid tropics have major influence on the distribution of natural endowments-soils, rainfall, and climate. These areas are well supplied with radiant cnergy, but because of variations in the weather system and orographic influences, a variety of rainfall patterns are produced. Because of the high evaporative demand during most of the growing season, variations in the timing and amounts of precipitation are generally the key factors influencing the agricultural-production potentiality of a given SAT region.

Weather at ICRISAT Center

This year both the onset and withdrawal of the rainy season were earlier than normal. This facilitated the timely planting of rainy season crops, but adversely affected the seeding of postrainy season crops, which was delayed. The total amount of rainfall received during the year was near normal at 752 mm (normal is 800 mm). Monthly totals of precipitation recorded from June 1976 to May 1977 are compared with long-term averages in Table 46. July and August received respectively 30 and 90 percent more rainfall than average, while September received only about 40 percent of the average. These data once again show that rainfall in the SAT is quite

Table 46. Average monthly rainfall and rainfall received during 1976-1977 at ICRISAT Center.

Month	Average rainfall	Rainfall
	(mm)	(mm)
Jun	115.5	86.0
Jul	171.5	219.3
Aug	156.0	298.7
Sep	181.0	74.0
Oct	67.0	0.6
Nov	23.5	29.7
Dec	6.0	
Jan	5.5	
Feb	11.0	
Mar	12.5	
Apr	24.0	7.5
May	26.5	36.0
Total	800.0	751.8

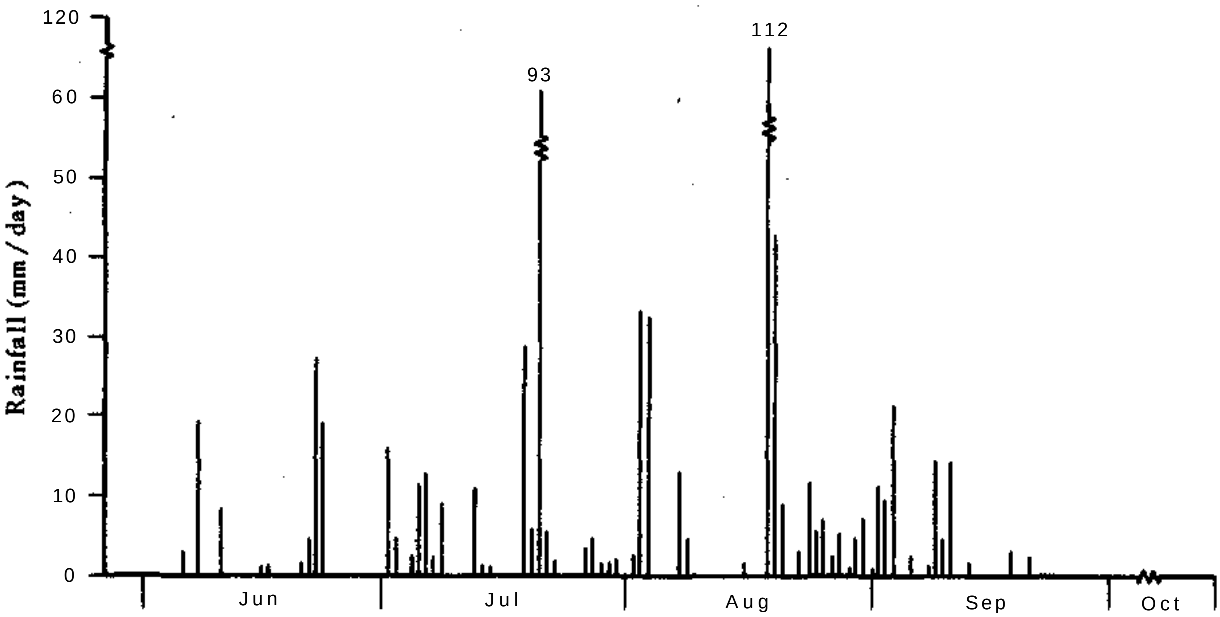


Figure 50. Daily rainfall at ICRISAT Center, 1976.

erratic and undependable. It also confirms the findings reported on rainfall dependability for Hyderabad in the 1975-1976 Annual Report. It was shown that, though September is the rainiest month, the dependability of rainfall is lower in September than in July.

During the postrainy season (Oct-Feb) of 1976-1977, very little rainfall was received (30.3 mm; normal 113 mm). The growth and development of postrainy season crops were adversely affected due to the resultant atmospheric drought and relatively higher temperatures. The dependability of rainfall during this period is quite low; the amounts received from year to year vary widely.

Daily and weekly values of precipitation received during the 1976 rainy season (Jun to Oct) are shown in Figures 50 and 51. The maximum amount of rainfall received during one single day was 112 mm in August; there was a 93-mm rain in July. There were ten occasions when rainfall was in excess of 20 mm/day and 19 occasions when it exceeded 10 mm/day. Set on standard weeks (Fig 51), the highest weekly total was 132 mm for week No. 29 (16-22 Jul). This amount of rainfall is about three times the average value based on

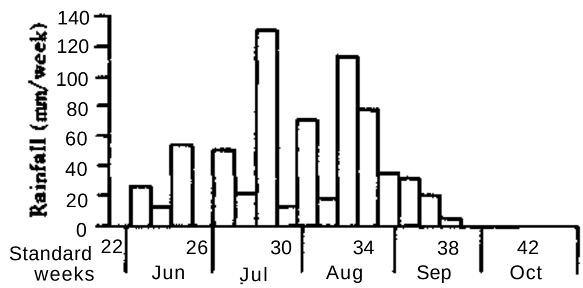


Figure 51. Weekly rainfall at ICRISA T Center, 1976.

70 years' data and it is six times the dependable rainfall expected at 75 percent probability.

The monthly amounts of rainfall recorded for the past 5 years are shown in Figure 52 for the rainy season period extending from June to October. The dispersion of curves clearly shows that the early period of the rainy season, i.e. June and July, is somewhat more stable compared to the months of August, September, and October.

The distribution and the amounts associated with high-intensity rainfall recorded during 1976 are shown in Figure 53. During rainy season 1976, there were 58 rainy days recording more

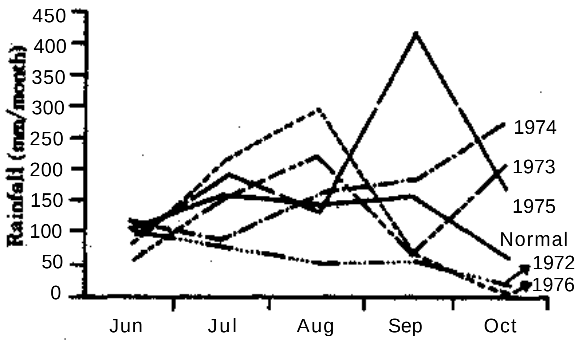


Figure 52. Monthly rainfall at ICRISAT Center, 1972-1976.

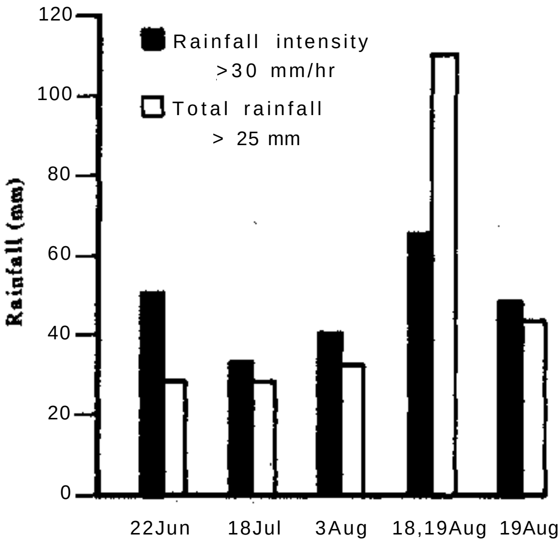


Figure 53. Rainfall intensities and total rainfall of selected storms at ICRISA T Center in 1976.

than 1 mm rainfall. There were two August storms with an intensity exceeding 50 mm/hr. The first was a 60-mm rainfall in one hour near midnight on 18 Aug, followed by a second storm of 32 mm in 30 minutes just after midnight. The two high-intensity rains were separated by about half an hour.

The large number of rain-gauge stations distributed over 1394-ha ICRISAT Center permits the close examination of the uniformity of rainfall. The observations showed that the September rainfall was fairly well distributed while the early rain in June was highly localized and nonuniform in distribution.

In semi-arid areas, extreme variation in rainfall can be encountered even over a small area. A comparison of the spatial distribution of rainfall (total seasonal Jul-Sep) at ICRISAT Center for the years 1974, 1975, and 1976 revealed wide variations. In 1975 the total rainfall varied from 1000 to 1 300 mm. The variation was much less in 1974 and 1976. The data for 22 August 1976 showed a variation from 1.4 to 65.6 mm in N-S direction, demonstrating that rain gauges should be located close to each experiment if quantitative evaluation of the moisture regime is desired.

The trends of weekly mean maximum-minimum temperatures for 1976-1977 are shown in Figure 54. A maximum of 41°C (106°F) was recorded on 21 May and the minimum of 9°C (48°F) recorded on 30 January 1977. The daily maximum temperatures generally ranged between 25 to 30°C during both the rainy season and the postrainy season. The daily minimum temperatures ranged between 20 and 25°C during June through early October, and between 10 and 20°C from mid-October to February.

Soil thermometers were placed at depths of 1 to 150 cm in a grassed Vertisol and readings recorded twice daily (thermometers embedded at 100- and 150-cm depths were read only at 0717 hours). Observations for various depths are plotted in Figures 55a and b. In the surface 30 cm, there was little difference between the morn-

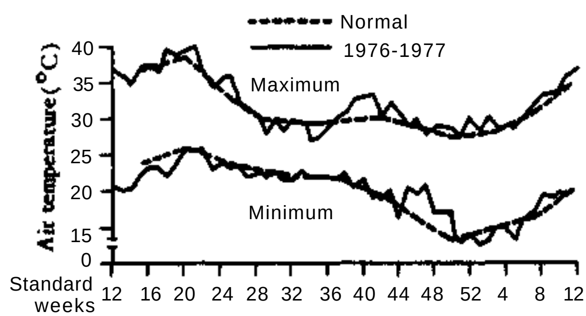


Figure 54. Weekly average maximum and minimum air temperatures at ICRISAT Center, 1976-1977.

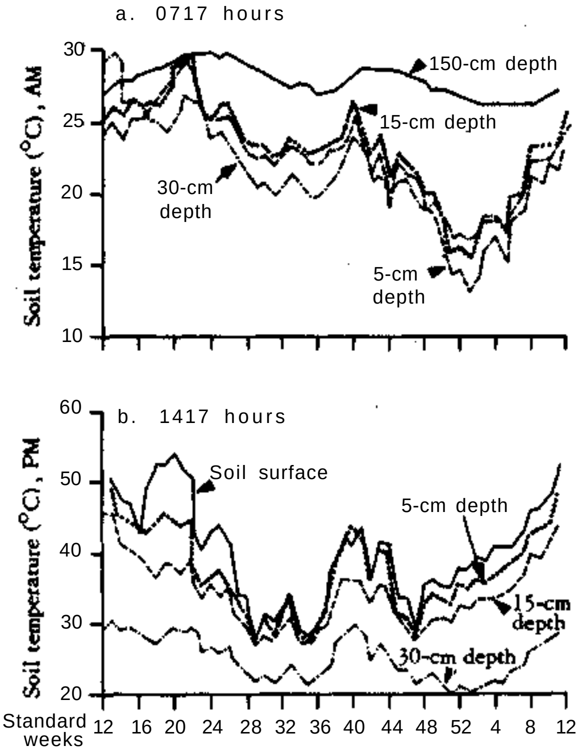


Figure 55. Weekly average soil temperatures, recorded at 0717 and 1417 hours, at ICRISAT Center, 1976-1977.

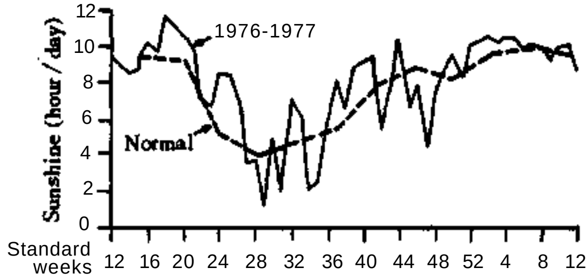


Figure 56. Weekly average hours of bright sunshine at ICRISAT Center, 1976-1977.

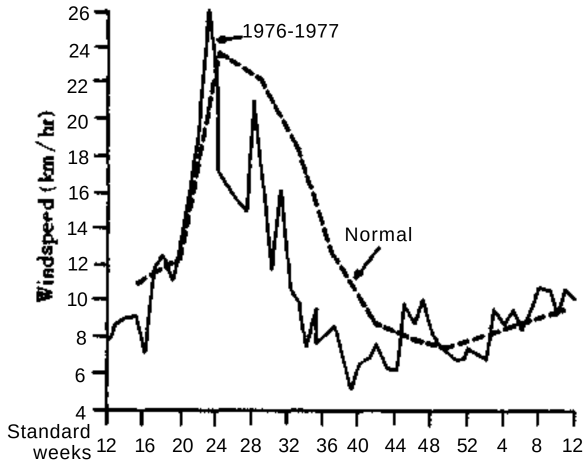


Figure 57. Weekly average wind velocities at ICRISAT Center, 1976-1977.

ing values. However, in the afternoon, variations at different depths are more pronounced. Seasonal variations in temperature at shallow depths are clearly shown.

The average weekly hours of sunshine at the ICRISAT agri-meteorological observatory in 1976-1977 are plotted in Figure 56. During July and August, relatively fewer hours of bright sunshine (on an average < 6 hours) were recorded, while > 9 hours were observed from the middle of September to March except on some days in November, when there was cloud cover.

Average weekly wind velocities, recorded at the 3-meter height, are plotted in Figure 57. The period between April and July was quite windy, with average daily wind speeds in excess of 10 km/hr frequently observed. The prevailing wind was from the west during this period. A maximum daily average wind speed of 33 km/hr was recorded on 7 June 1976. During September-March, the prevailing wind was from the east in the afternoon and from the south in the morning.

Weekly means of the relative humidity, recorded at 0717 and 1417 hours, are plotted in Figure 58. The relative humidity values in the morning were above 70 percent for the period between June to January. However, the values exceeded 70 percent at 1417 hours during one week in July and in August.

The class-'A' pan evaporation data read daily at 0830 hours are shown in Figure 59. Rates of 4 to 6 mm per day were observed during the period mid-July to late January. Evaporation rates above 10 mm/day were frequently observed during April to June, with the maximum daily evaporation of 14.1 mm recorded on 28 April and again on 30 April.

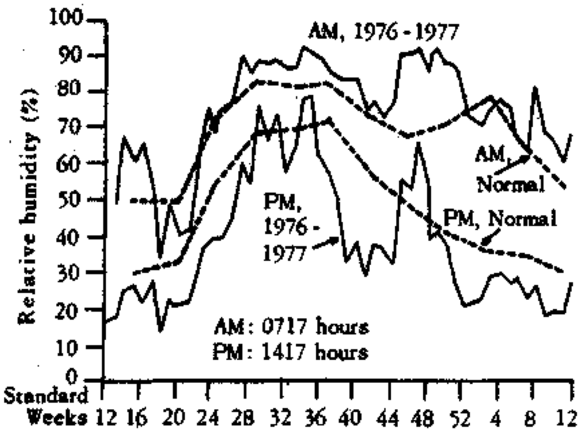


Figure 58. Weekly average relative humidity at ICRISAT Center, 1976-1977.

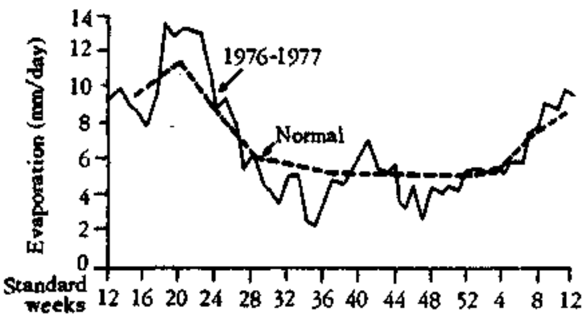


Figure 59. Weekly average evaporation at 1CRISAT Center, 1976-1977.

Dew was recorded in November, December, and January. Total for the period was 3.5 mm.

Characterization of Rainfall Patterns in the SAT

Average monthly, seasonal, and annual rainfall data based on long-term weather records, are generally used for assessing the precipitation characteristics and length of the humid season. Several workers (Thornthwaite, 1948; Troll, 1965; and Cocheme and Franquin, 1967)[1] have used comparisons between average rainfall and evapotranspiration to arrive at conclusions regarding moisture availability of crops. Recently, Hargreaves (1975) suggested that due to great variability of rainfall in the tropics, the climatic moisture availability to crops should be based on a comparison of dependable rainfall (amount of rainfall expected with 75% probability) and potential evapotranspiration. Robertson (1976) used the Markov-chain method to analyze dry and wet spells for defining rainfall distribution in monsoonal Malaysian tropical areas.

[1]References for this section are listed on page 197.

To compare the relative usefulness of the above methodologies for characterizing rainfall in SAT conditions, we selected two adjacent areas of India-Hyderabad (17°27'N) and Sholapur (17°40'N) situated nearly 500 km apart. Both are in the Vertisol soils region. Other characteristics are listed in Table 47.

Study of rainfall, moisture index, and length of the growing season for the two locations from generalized annual, seasonal, or monthly data shows that the areas are quite similar agroecologically. On similar soils (e.g. deep/medium deep Vertisols), therefore, one would expect somewhat similar agricultural potentialities. However, results of. farming/cropping systems research carried out at Sholapur Research Station of the All-India Coordinated Research Project for Dryland Agriculture and at ICRISAT Center over the past 5 years or so reveal the following:

At Hyderabad it is possible to obtain yields in excess of 5 metric tons per hectare by adopting pigeonpea/maize intercrop or maize/chickpea sequential crop combinations under good agronomic management (rainfall-use efficiency is of the order of 6 to 10 kg/mm), whereas at Sholapur rainy season cropping is fairly undependable. A short-duration crop of pearl millet followed by a sorghum grown on conserved moisture is successful at Sholapur. But yields from year to year are highly variable and rainfall-use efficiency at Sholapur is quite low.

The aim, therefore, is to characterize the rainfall climatology that is agronomically relevant. We selected short-term climatic (weekly) data instead of month/season or annual data. The rainfall amounts have been characterized in

Table 47. Climatic characteristics of the Hyderabad and Sboiapur areas of India.

Characteristic	Hyderabad	Sholapur
Mean annual rainfall (1931-1960)	764 mm	742 mm
Proportion in Jun-Sep	76 %	75 %
Annual mean PE	1757 mm	1802 mm
Moisture index[a]	-56.4	-58.7
Growing season[b]	12 Jun-8 Nov (130 days)	8 Jun-22 Nov (148 days)
H + M[c]	130 days	140 days
H + M + MD	170 days	165 days
Climatic classification:		
Troll's	Dry semi-arid	Dry semi-arid
Hargreaves'	Semi-arid	Semi-arid

[a]Thornthwaite's. See Rao et al (1971 a).
[b]K.rishnan(1974).
[c] According to Cocheme and Franquin's method. See Raman and Srinivasamurthy (1971).

relation to their relevance for crop water availability. Once the crop is planted, the water requirement is fairly continuous, and hence the conditional probabilities of rainfall occurrence are important.

Analysis by Markov-chain model for initial and conditional probabilities of R/PE>0.33 meets most of the requirements as shown by the plots (Fig 60) for Hyderabad and Sholapur.[2,3] It is evident that rainfall distribution at Sholapur is highly erratic, as only a couple of dispersed points of initial probability exceed the 70-percent threshold. The conditional probability of wet period followed by wet period [P(W/W)] also follow a fairly similar pattern. In comparison, Hyderabad rainfall analysis shows that it has a dependable rainfall distributed between 18 June and the end of July and from about mid-August to mid-September. This clearly. brings out that rainfall during the rainy season cropping period at Sholapur is highly erratic and therefore undependable and is probably one of the major environmental factors that has led to low agricultural-production efficiency in that area. Hyderabad seems to have much more favorable climate for crop production during the rainy season.

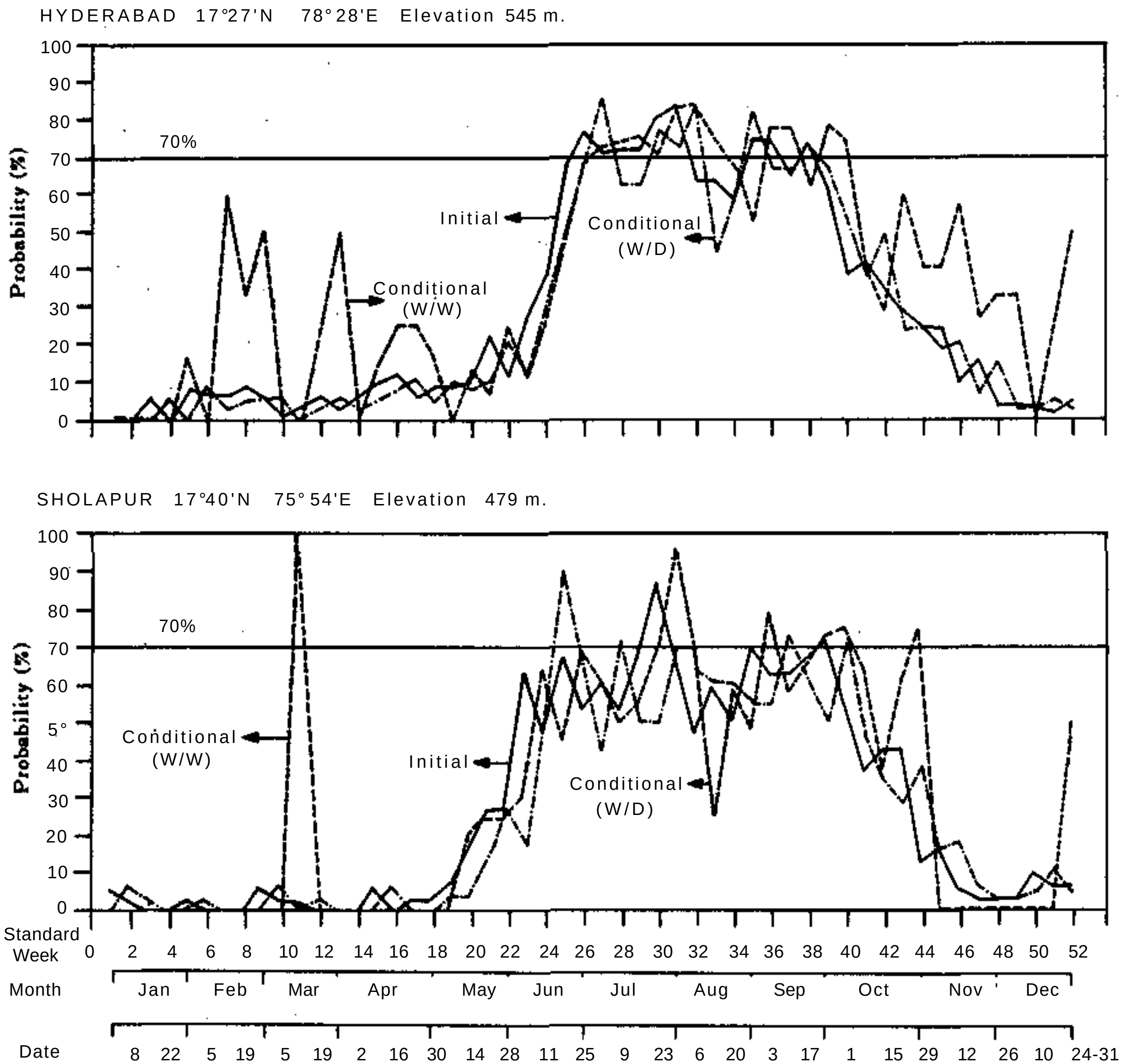
[2]R/PE (The rainfall/potential evaporation ratio) is called the Moisture Availability Index (MAI); dependable rainfall is considered to be the criterion.

[3] India Meteorological Department has published PE values for most of the districts in the subcontinent. See Rao, et al. (1971b).

Additional agronomically relevant information that such an analysis reveals, (Fig 60) is as follows:

(i) In Hyderabad, onset of the cropping season is fairly consistent around mid-June. So dry seeding in Vertisols is a feasible practice. In Shoiapur, such a practice cannot be recommended because of uncertainty as to when the rains will start.

(ii) At Hyderabad, it is evident from the rainfall-probability analysis that midseason breaks in the continuity of rainfall are likely to occur on an average of 4 to 6 years of a 10-year period. Obviously one would not select a crop cultivar that would be in an active phase of growth during this period. Either a sole short-duration crop (which can be expected to complete most of its life cycle prior to the break in rainfall) or a long-



Figwe 60. Initial and conditional rainfall probabilities of RIPE > 0.33 at two selected Indian SAT locations.

duration base crop with a short-duration intercrop would be best suited for the Hyderabad environment.

(iii) The rainfall analysis for Sholapur shows that crops with indeterminate nature and drought-hardy crops would be more suitable, whereas at Hyderabad one could probably select determinate or even drought-sensitive crops, depending upon soil conditions.

(iv) The cost/benefit ratio for recycling of runoff water would be much more favorable in the Sholapur region when compared (for similar soil types) to Hyderabad.

(v) The wet/wet probabilities of rainfall at either location show that in about 4 of 10 years, rainfall has a tendency to continue after the normal date of recession. Crops sensitive to wet weather at maturity should not be selected, particularly in the Vertisols.

The above comparison between Hyderabad and Sholapur is just one example of the employment of climatic data for selecting crops or varieties to suit the weather. Depending upon the nature of the investigator's interest, such a procedure could be used for any station (for which data is available) for planning several cultural practices-including selection of methods of land layout, seedbed preparation, selection of sowing dates and methods of sowing, weeding, degree of mechanization, and type of equipment to be used.

Hydrology

In most farming systems of the SAT, only a relatively small portion (about 20 to 50 %) of the annual rainfall is actually used for crop production. To determine the potentials for improvement, the Hydrology subprogram is concerned with the fate of all water, not only that which is immediately available in the crop root zone for evapotranspiration, but also that which runs off or drains to deeper layers beyond the root profile. Although considerable information is available on the hydrology of large catchments with perennial vegetation, our knowledge of the actual water balances of small agricultural watersheds is fragmentary. Most hydrologic studies at ICRISAT are conducted as part of watershed-based resource utilization research or of cooperative research. The objectives of the Hydrology subprogram are:

(i) To contribute to the quantification of runoff probabilities, groundwater hydrology, and erosion behavior under alternative management treatments in agricultural watersheds for various agroclimatic zones.

(ii) To assist in the development of hydrologic models and simulation programs for the interpretation and extrapolation of hydrologic research findings to major agroclimatic zones.

(iii) To develop methodology and equipment for hydrologic research.

Sediment Distribution and Runoff Sampling

Measurements of sediment density variation during runoff events show that considerable error in erosion estimates might result when these are based on few samples (Fig 61). Sediment concentrations at relatively brief peak times may be twice as large as those observed during most of the remaining part of a hydrograph. The vertical sediment distribution at the converging and diverging sections of Parshall flumes was determined for Vertisols and Alfisols. The distribution of suspended particles at different flow depths was relatively stable on Vertisols. However, a greater variation was observed for Alfisols; this is presumably caused by a larger fraction of coarse sediment in eroded material from such soils. Thus, accurate erosion estimates require sampling at frequent intervals and several flow depths during a runoff event. Two different types of sediment samplers, based on these requirements, are presently being tested on research watersheds (Fig 62).

Observations on the Runoff Process in Small Watersheds

Preliminary studies on modelling and simulation of the runoff process characterizing small agricultural watersheds have shown the overriding importance of rainfall intensity and canopy development. The effect of the weighted mean intensity (WMI)[4] of storms on the rainfall-runoff conversion system during two distinct crop canopy periods in the rainy season on BW1 (150-

[4] To determine WMI, a storm of varying rainfall intensity is subdivided into sections of similar intensity $I_1, I_2, ...I_n$; if the precipitation in these sections is R_1, $R_2, ...R_n$, then

$$WMI - [(I_1/R_I) + (I_1/R_2)+....(I_n/R_n) /(R_1+R_2+....$$

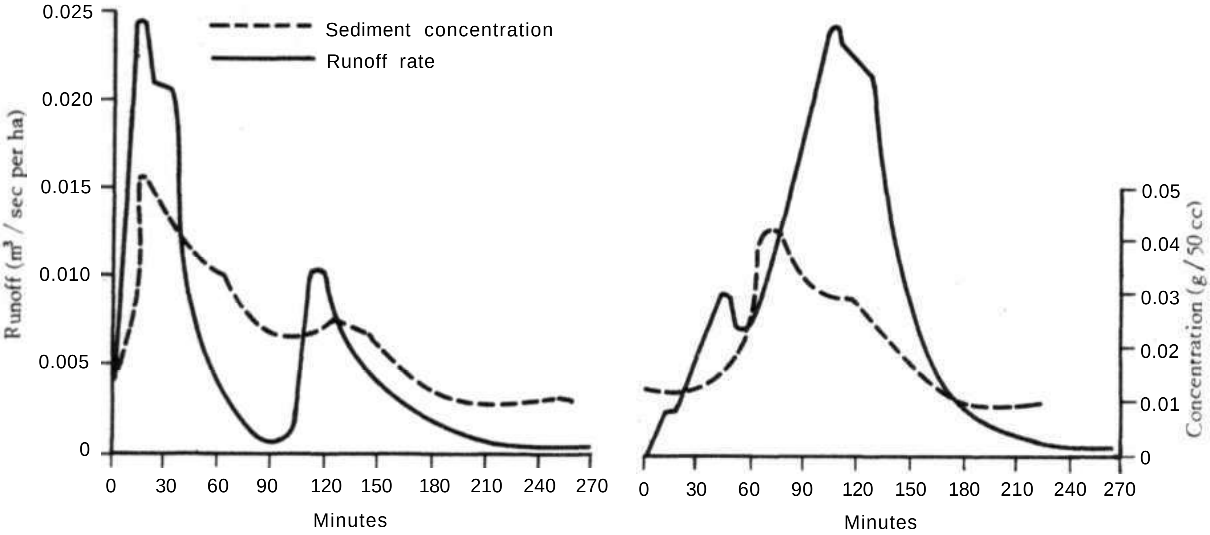


Figure 61. Sediment concentration and runoff rate during two storms on watershed BW1.

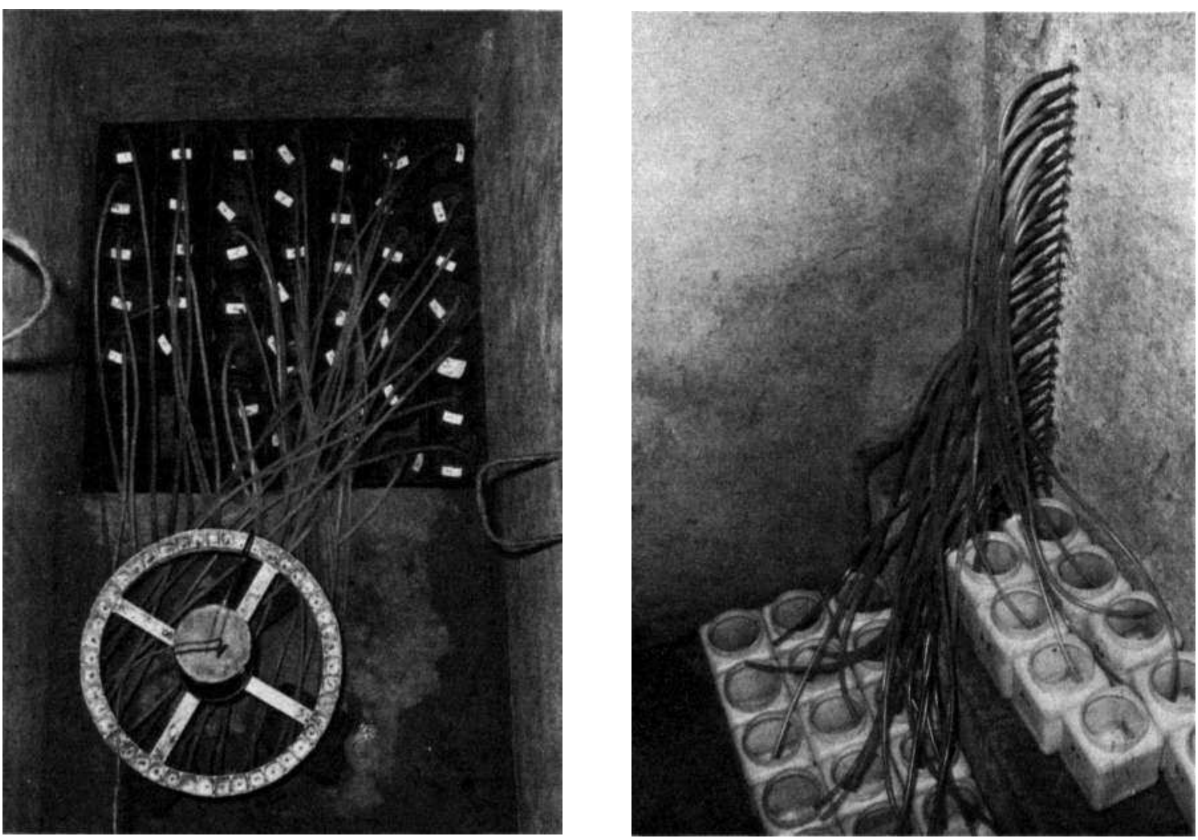


Figure 62. Two types of sediment samplers being tested for research on the watersheds.

cm bed at 0.6 % slope) and BW4 C (rainy season fallow, field bunded) is plotted in Figure 63. In the preemergence and canopy-development stage (from emergence to about 20 July), cropped watersheds show a greater sensitivity to high-intensity storms than when a full canopy is present. Comparing the runoff behavior on BW1 with that observed on BW4C, it is evident that although bedded cultivation systems appear effective in reducing runoff up to a WMI of about 25 mm/hr, at greater intensities both watersheds react similarly.

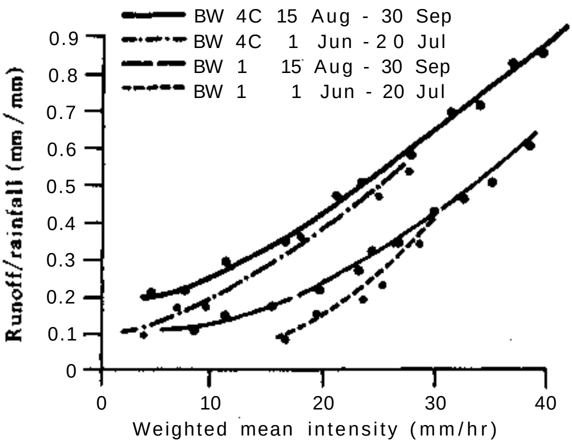


Figure 63. Effect of rainfall intensity and crop canopy on runoff.

Soil Physics

The purpose of the Soil Physics subprogram is to provide a quantitative description of the physical state and dynamics of water during its passage through the soil-plant-atmosphere continuum. The research is 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.

Physical Characterization of Alfisol Profiles

Alfisols have a large number of stones distributed throughout the profile; hence, sampling for bulk density using a core sampler 2 inches in diameter is not feasible. The bulk density and stoniness of an Alfisol profile was studied by taking 15-cm-thick samples to a depth of 180 cm with a 30- x 30-cm metal sampler. Three sets of such samples were taken from a pit dug in the RW3 area. The results are summarized in Figure 64.

Infiltration in Alfisols and Vertisols

Four sets of square concentric iron frames (1.5 x 1.5 meter inner, 2.4 x 2.4 outer) were used to run infiltration experiments on the Alfisols of RW1 and RW3 and the deep Vertisol of BW5. The 45-cm buffer zone between the frames prevented horizontal flow of water from the inner ring. A water head of 3 cm was maintained

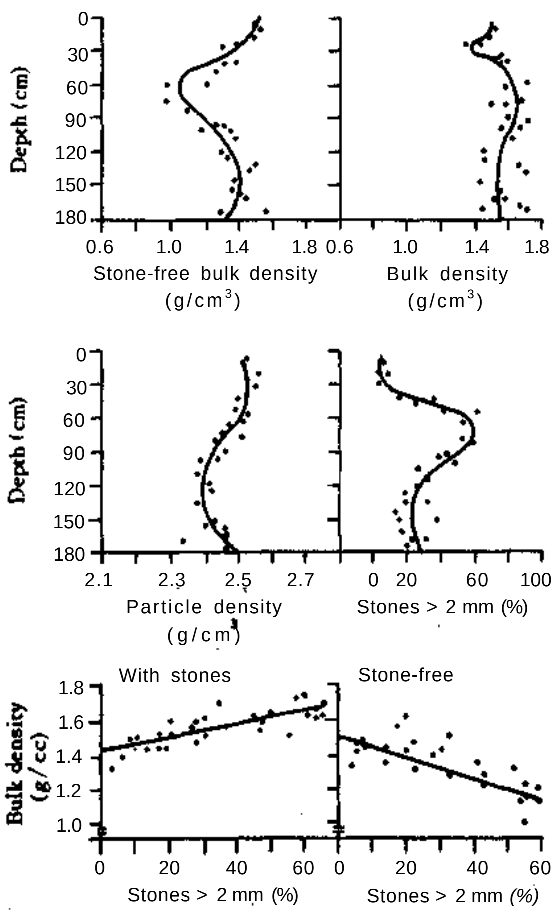


Figure 64. Bulk density, particle density, and percent stones in Alfisols.

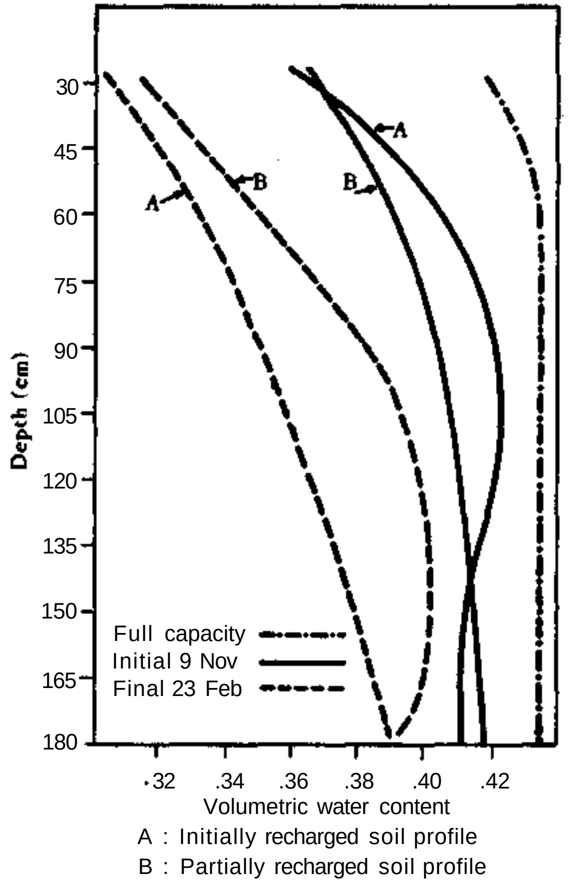


Figure 65. Initial and final moisture profiles of differentially charged soil profiles.

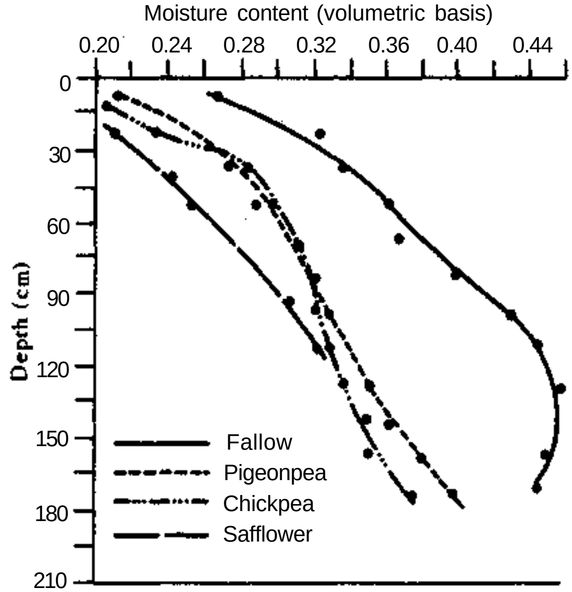


Figure 66. Moisture profiles at crop harvest in deep Vertisols.

postrainy season crops of pigeonpea, chickpea, and safflower. The end-of-season profiles (Fig 66) reveal that the surface 30 cm was depleted below the 15-bar percentage. In the 30- to 180-cm section, slopes of the residual moisture profile were roughly the same for the different crops. About 40 percent of the "available" water (field capacity minus 15-bar percentage) in the 30- to 180-cm section was not used by the crops. It is suggested that this end-of-season moisture profile may be a better indicator of the "crop extractable" water on deep Vertisols than the traditionally used "available" water.

Assuming that the deep Vertisol profile was fully charged at the beginning of the season, 115 mm was used by the postrainy season crops, 40 mm was lost by evaporation, and 50 mm was left as residual moisture in the 30- to 150-cm section. The 0- to 30-cm layer lost about 50 mm, much of it by evaporation. An unmeasured but perhaps agronomically significant amount of moisture is believed to have moved upwards into the rooting zone from depths below 180 cm. This assumption is supported by tensiometer data that showed upward hydraulic gradients in excess of five times gravity in the 150- to 180-cm section during extended periods of time beginning in November.

Conclusions

From the experiments conducted and data obtained during the past year, it was concluded that the physical properties and processes which govern the retention and movement of water in the soil-plant-atmosphere continuum can be measured with reasonable precision. These measurements can be used for field studies of the water balance, time and depth pattern of profile-water depletion, and crop water-use efficiencies on the deep Vertisols; however, further work will be required to develop means of coping with the

Table 48. Effect of row spacing and nitrogen application on sorghum upon grain yields of sole and intercropped sorghum and pigeonpea on a Vertisol* at ICRISAT Center, 1976-1977.

Crop	Row spacing	Zero N on sorghum		60 N on sorghum	
		Yield	LER	Yield	LER
	(cm)	(kg/ha)		(kg/ha)	
Sole sorghum	45	1530		3520	
Sole sorghum	90	1760	-	3320	-
Sole pigeonpea	45	1540		1370	
Sole pigeonpea	90	1400		1370	
Intercropping (alternate rows 45 cm)					
Sorghum		1660	1.01	2980	.87
Pigeonpea		1050	0.71	920	.67
Total Land Equivalent Ratio (LER)			1.72		1.54

L.S.D. (0.05) sorghum-1060; pigeonpea-310.

[a]Available, N, P. and K prior to fertilization:
0-to 15-cm depth, 78, 6.0, and 356 ppm, respectively
15-to 30-cm depth, 63, 1.1, and 237 ppm, respectively

This is a 4-year experiment, and some of the treatments have had only their first annual application. Some preliminary information was obtained, however. In the sorghum series, 10 and 20 kg/ha of P as super phosphate and 30 ton/ha of FYM (farmyard manure) gave significant yield increases. In all other treatments there was a positive trend, but it was not significant. The pearl millet yield was extremely low due to extreme drought in September and October and there was no significant difference in pigeonpea yields (Table 49).

An experiment was initiated to evaluate the response of chickpea genotypes to phosphorus on a Vertisol. Ten promising genotypes from chickpea breeders were tested at four levels of P (0, 10, 20, and 40 kg/ha).

Since this was the first crop grown after clearing the land, the average yield levels were very low (320 kg/ha). There was a small but significant response to phosphorus application. The genotype mean yields were significantly different, but the interactions between P levels and genotypes were not significant.

Seasonal Changes in Nutrient Status

A better understanding of seasonal changes in nutrient status throughout the year under various soil and crop management systems is vital to the development of management systems for crop residues and organic wastes, as well as for arriving at soil- and water-management practices which optimize nutrient availability to crops and minimize losses. There is some evidence of a buildup of nitrate in the soil profile during the noncropped season prior to the rainy season (Krantz, et al. 1944 and Wetselaar, 1961a). In order to study this phenomenon on a year-around basis, a soil sampling program to measure the seasonal changes in nitrate nitrogen and "available" N in the upper 90 cm of a Vertisol and an Alfisol was initiated.

To obtain a statistical measure of the vari-

Table 49. **Sorghum and pearl millet/pigeonpea intercrop grain yields as affected by different treatments on an Alfisol at ICRISAT Center, 1976-1977.**

Treatment	P applied	Sorghum	Intercropping Pigeonpea	Intercropping Pearl millet
	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
1[a]	0P	680	620	340
2	20 P as Phosphate Rock	930	660	320
3	40P	850	790	400
4	80P	770	710	480
5	160P	1270	580	220
6	80 P Phosphate Rock + Sulphur in Pellets	1100	690	350
7	80 P " +30 tons/ha FYM mixed	1600	740	490
8	80P " +5P(SP) banded	1160	700	480
9	5 P as Super Phosphate (SP) banded	1280	760	430
10	10P	1790	750	420
11	20P	2040	610	580
12	30 Tons/ha FYM	1710	850	540
L.S.D. (0.05)		660	-	-

[a]Available N, P, and K prior to fertilization:
0- to 15-cm depth, 80, 2.8, and 126 ppm, respectively
15- to 30-cm depth, 94, 3.6, and 108 ppm, respectively

ability, soil samplings were taken in each of the four replicates of the "Steps in Improved Technology" experiment. Four treatment combinations involving local vs. improved fertilization and management, plus a fallow plot, were sampled. Soil samples were taken at 0 to 15,15 to 30, 30 to 60, and 60 to 90 cm at monthly intervals from an area of 9 x 12 m in size in each treatment. Each sample consisted of a composite of 10 subsamples taken at random. The samples were immediately treated with toluene, dried at 60°C, and thoroughly mixed. A 5-g sample was then extracted with $CuSO_4$ and the nitrate nitrogen Concentration determined on a 5-ml aliquot of extracting solution by the phenol disulphonic acid method.

This investigation was started in July 1976 and will be continued for several years in an attempt to establish a trend in seasonal status of nitrate and available nitrogen in these soils. Early samplings indicate large variability in nitrate concentration with depth and time. Thus, large numbers of replications and repeated samplings will be necessary to establish reliable trends. The present data will be combined and summarized with next year's data and reported at that time.

Boron Toxicity on Ratooned Pigeonpea

Severe necrosis of the leaf margins in ratooned pigeonpeas was observed in March 1977. The symptom was the most severe on the oldest leaves and graded to no symptom on the youngest leaves. The affected areas, which occurred in spots in fields ST1 and BW8 C, also showed depressed plant growth. Pigeonpea leaf samples taken at random within the affected areas showed high levels of boron in all cultivars. The average was 393 ppm B vs. only 151 ppm B in the leaves of "normal" plants from adjacent areas.

The average water-soluble boron content of the 15- to 90-cm soil depth showed that the boron level in the affected areas (1.50 ppm) was twice that in normal soil (0.72 ppm). There were also more sodium and other soluble salts in the "affected" soil compared to the normal soil, but these were not reflected in the analysis of plant samples.

Toxicity symptoms did not occur during the rainy season or early postrainy season. Their appearance on the nonirrigated ratoon crop during the February-March period is believed to be due to increase in boron concentration in the soil solution due to the reduction in soil moisture and also due to greater moisture extraction from the lower depths (where boron levels are higher) as a result of the drying of the surface soils.

ICRISAT's pulse physiologists induced the same symptom in potted pigeonpeas by adding increments of boron to the soil. This is the first known case of boron toxicity in pigeonpea.

Farm Power and Equipment

During the past year the staff of this subprogram has been expanded with the addition of a principal scientist and two engineers. The Farm Power and Equipment subprogram is attempting to define and develop power-machinery systems for different levels of improved management. These systems have to be technically feasible and economically viable. Specific objectives and orientation of this subprogram are still evolving and considerable time has been spent in project development. The following five projects have been conceived and will be undertaken as facilities, equipment, and staff are developed:

1. Determination of available power and machinery resources and the requirements for improved farming systems in the SAT.
2. Development of improved tillage and planting techniques and equipment and machinery systems.
3. Development of improved harvesting techniques and equipment and machinery systems.
4. Effective utilization of available power and generation of new sources of power and energy.
5. Determination of design criteria, standards, and cost estimates for the manufacture of selected farm equipment and small mechanical power units and design of testing equipment.

Equipment Development

A major emphasis of the subprogram is to modify, adapt, and evaluate existing implements which can play an important role in improved farming systems. In order to provide the proper focus to the subprogram and to avoid duplication of work being conducted elsewhere, a survey is being organized to ascertain available equipment as well as current and past research and development on machinery and implements suitable for small-scale farmers in the SAT. An effort will also be made to determine future needs of farm power and equipment for this group of farmers. The survey is being organized jointly by ICRISAT and the International Livestock Centre for Africa (ILCA). Major emphasis will be placed on Africa and Asia.

The machinery-development phase was greatly aided by the assistance of Mr. Jean Nolle, a designer of considerable experience in animal-drawn machinery. Most of his efforts were spent on modifying and improving the "Tropiculteur" for use in the farming systems being developed at ICRISAT for Vertisols and Alfisols. This wheeled tool carrier was described in ICRISAT's Annual Report for 1975-1976.

Since the 150-cm bed-and-furrow system has been adopted in the watershed-based resource utilization research, it was necessary to adapt and modify equipment for making these. Where the soil had been previously tilled, a ridger body was set at each end (150 cm apart) of the toolbar. An oblique deflector was attached behind each ridger inclined towards the center to form the ridge. This provides a slight crown, which is desirable to provide proper drainage of the bed. Figure 67 shows broad beds being re-formed for the third year. For interrow cultivation, a steerable toolbar is used (Fig 68). The animals and implement wheels in all operations move in the furrows.

It is relatively common in the SAT to use two-wheel carts with various animals. In some cases a four-wheel trailer replaces the two-wheel cart. This has the advantage of being able to carry a much heavier load and to remove the vertical force from the necks of the animals. Such a trailer was designed to fit on the tropiculteur, using the tropiculteur as the two front wheels and frame for the trailer. A turntable is mounted on top to provide steerage. A frame with rear wheels completes the vehicle. This trailer can be fitted with various attachments for handling produce or to carry pipes used for supplemental irrigation (Fig 69).

Tillage Requirements

Tillage, including mechanical weed control and seedbed preparation, usually requires much power in the production of most annual crops. Thus it is desirable to minimize tillage as much as

Figure 67. Broadbeds being re-formed for the third year on an Alfisol at ICRISAT Center.

possible. Excess tillage tends to accentuate the formation of crusts, particularly on Alfisols. Efforts will be concentrated on determining the tillage requirements and defining the physical characteristics desirable in a seedbed. On Vertisols it has been observed that beds are sufficiently friable to be plowed during the early dry season; at these times flat-planted areas become very hard and very difficult and costly to till. Tillage studies to quantify these observations are planned.

Planting Requirements

"Ebra" seeders, made in France, were used for planting all crops (except pearl millet) at ICRISAT Center. These machines use an inclined rotating plate as a metering mechanism, and prior to the 1977 planting season the plates were modified for the seed size and seeding rates of the cultivars being planted at ICRISAT. This involves having a plate correct in thickness, hole size, and spacing in relation to the drive wheel. These unit planters, each with its independent drive wheel, provide a convenient method of planting two or more intercrops simultaneously. Compared with available planters, the French-manufactured machines provide a considerable degree of precision planting for the small-scale farmer. The major requirement of a good seeder is to meter the required amount of seed at uniform intervals and to place the seed in proper contact with moisture for quick germination. This involves having the required metering mechanism, furrow openers, covering devices, and press wheels. Experience in the past year

Figure 68. Interrow cultivation of intercrops on a Vertisol.

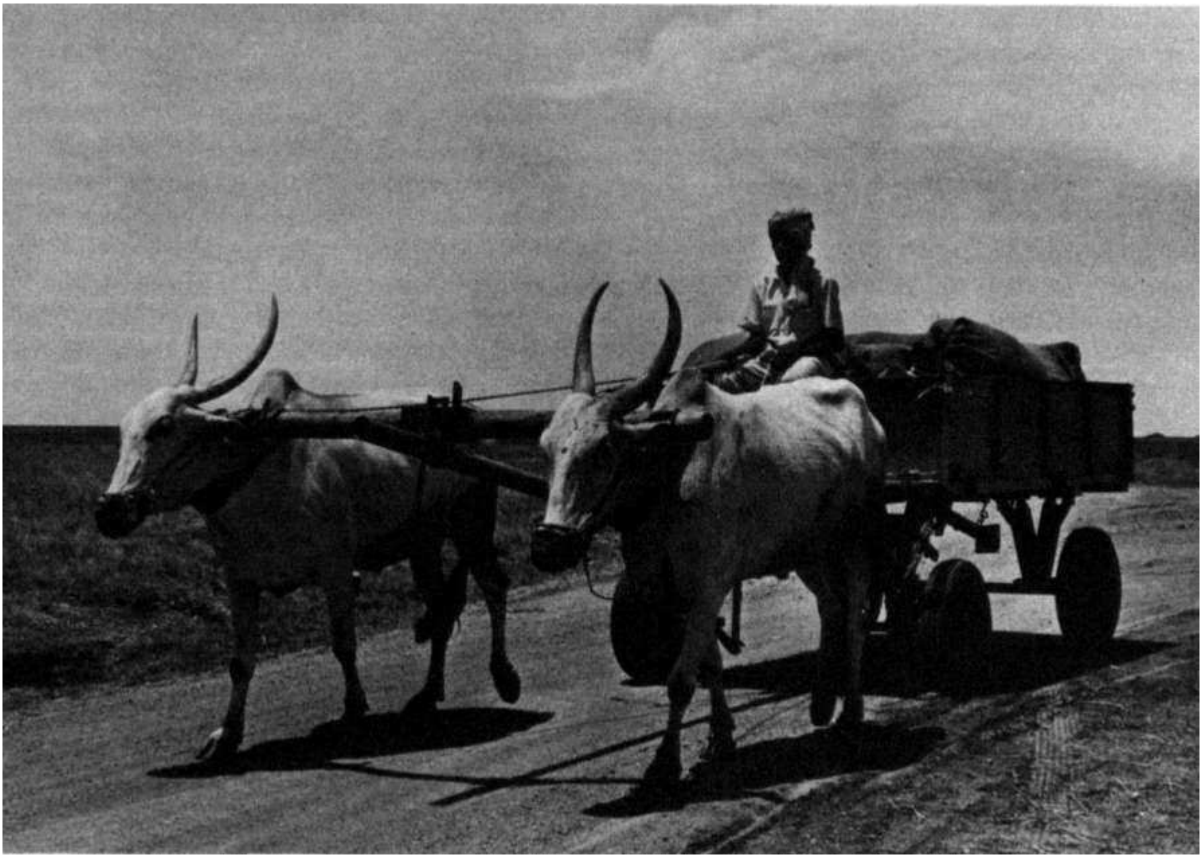


Figure 69. Four-wheel semitrailer, using the tropiculteur as the front wheels.

indicates a need for further development and studies in these areas.

Energy Sources in the SAT

Power or energy is often a major constraint to agricultural production in the SAT. In some areas, particularly parts of Africa and northeastern Brazil, the size of the area cropped each year is determined by the available human power for certain critical operations. Mechanical, animal, and human power are all being used in various parts of the SAT, usually in various combinations. It is important that equipment should be available to properly perform all operations so that each power source can be utilized to its fullest potential. In the watershed-based resource utilization experiments, all operations from land development through interrow weeding are now being conducted with animal-drawn machinery; traditional and improved machines are being used. The improved machinery is being used for both the bed and the flat cultivation. Thus it is possible to compare machinery use in three farming systems. Human power is used for some of the intrarow weeding, fertilizer topdressing, and harvesting. Threshing and supplemental irrigation are done with mechanical power. These operations have provided considerable experience in the use of a variety of implements and have shown deficiencies, indicating a need for modifications. Since crops are being grown in the rainy as well as the postrainy seasons, timeliness is important to permit crops to be planted as early as possible in both seasons.

A study is being initiated to analyze all operations in the watersheds in terms of their mechanical, animal, and human power needs. This will help determine which operations have high energy requirements and merit particular attention in order to reduce power requirements and operating costs, and to decide which operations can best be done by mechanical, animal, or manual power.

A cropping calendar is being developed and time-series studies initiated to determine where power, equipment, and labor bottlenecks occur. This analysis provides the information needed to quantitatively compare power, equipment, and labor requirements for different crops and cropping combinations in a particular farming system.

Village-level Studies of Power and Equipment Requirements

To understand farmers' requirements, a cooperative project is being undertaken with the Economics program to evaluate farm power and machinery systems for selected traditional farming systems. The data collected by the Economics program in its village-level studies are being analyzed to assess the extent of utilization of available power and equipment sources under present farming systems. This will be followed by a study of the constraints to adoption of improved power-machinery systems.

Land and Water Management

The goal of the Land and Water Management subprogram is to assist national and regional research organizations in the development and implementation of improved resource management technology. Such technology must more effectively conserve and utilize the rainfall and the soil to facilitate the introduction of hew crop-production systems capable of maintaining greater productivity and assuring more dependable harvest. Most farms in the SAT are quite small and the farmers have very limited financial means. The attitude of farmers towards new techniques is conditioned by experience of uncertainty and risk. Methods for soil and water management, conservation, and use should be suitable for implementation in this situation and be associated with immediate and clearly visible impacts on the levels and stability of production. Major areas of land- and water-management research are:

1. Land-management technology providing an improved moisture environment for crops, runoff and erosion control, and (where necessary) increased infiltration of rainfall without causing drainage problems.

2. Surface-drainage techniques facilitating a better growth environment for plants and improving the workability of the soil without increases in erosion.

3. Design-criteria for waterway systems that will safely convey excess water from the land with minimum interference to agricultural operations.

4. Alternative technologies for use of available surface- and ground-water on rainfed crops, providing increased benefits through stabilization of crop production during the rainy season and by lengthening the growing season.

5. Improved systems for runoff collection and re-utilization along with utilization of groundwater to increase available water resources on a watershed basis.

Solutions of resource-management problems must be tailored to specific site conditions due to the diversity of environments in the SAT (climate, soils, crops, topography, etc.). Focus of the Land and Water Management subprogram is therefore on the development of principles, approaches, and methodologies, and on cooperative research projects and the training of research and extension personnel. Much of the land- and water-management research at ICRISAT is executed as part of watershed-based resource utilization research; small-scale studies of present and improved soil- and water-management technologies will be discussed in the following sections.

Evaluation of Present Resource-conservation Practices

Contour and field bunding are the most common techniques to conserve soil and water on rainfed lands in the Indian SAT. Although well-designed and maintained bunds undoubtedly conserve the soil (see Watershed-based Resource Utilization Research), their usefulness for moisture conservation which enhances crop production, particularly on heavy soils, is less certain. At each bund, one can distinguish a seepage area, a borrow pit, a zone where runoff is impounded frequently, a transition area intermittently under water, and a zone which apparently is not affected by the bund (Fig 70).

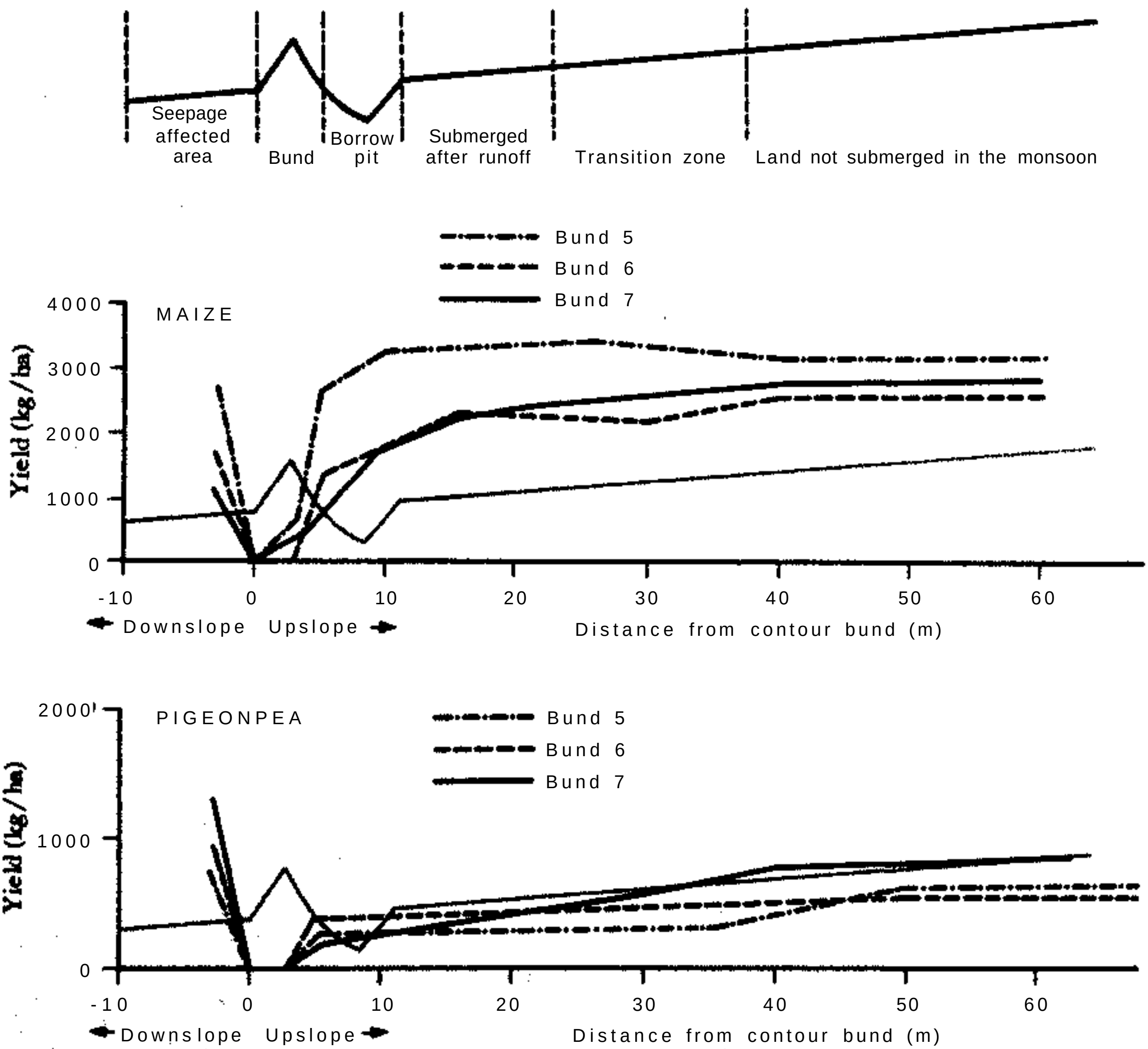


Figure 70. Effect of contour bunding on yields in a maize/pigeonpea intercrop on a Vertisol at ICRISAT Center, 1976.

The effects of three contour bunds on the yields of rainy season maize grown as an intercrop in pigeonpea are shown in Figure 70. These data were collected on Vertisol watershed units BW6 C and D; the relative land area occupied by bunds in this area amounts to about 3 percent, while the additional area affected by the bunds varies from 2.7 to 3.6 percent. At bund 5, crop yields in the submerged and transition areas exceeded those in nonaffected areas by about 10 percent; at bund 6, maize yields in the affected area were approximately 10 percent less than those farther away from the bund. At bund 7, yields near the bund were around 10 percent less than in nonaffected areas. Pigeonpea yields from the same areas are summarized in Figure 70. In all cases, yields in the submerged zone were less than in areas at greater distance from the bund. At bunds 5, 6, and 7, yields were reduced by 50, 30, and 60 percent, respectively.

The results obtained during the past season show a rather mixed effect of bunds on maize yields in the affected areas. During the rainy season of 1976, only three runoff-producing storms occurred and the rains terminated before the wet-season crops became mature in September. The waterlogging effects, frequently associated with contour bunds (Fig 71), were less serious than, for example, in 1975. However, the relative area influenced by bunds is often so small that the overall yield effect, even if positive, becomes marginal. An increase of 10 percent in maize yields of the intermittently submerged area at bund 5 contributed less than 1 percent to total yields because only 2.7 percent of the entire area is actually affected by the bund. Given these observations on contour bunds in a relatively low rainfall year, it appears that no substantial moisture-conservation effect on crop yields can be expected from this practice under most conditions in the SAT.

Figure 71. Waterlogged sorghum/pigeonpea intercrop above contour bunds.

Bed and Flat Planting

Runoff and soil erosion are processes which originate on cultivated land. Although mechanical protection structures such as bunds may serve as a second line of defense, the treatment of the land and/or cultivation methods are most critical in controlling the effects of high-intensity rainfall, particularly under conditions of limited crop canopy development, even when land slopes are moderate. Land levelling is costly and often requires large-scale equipment; also many of the soils in the SAT do not have the depth required for substantial earth movement. Therefore, a search was initiated to identify rather simple land treatments which could be implemented by the farmers.

Soil- and water-management and productivity aspects of several systems of land cultivation and planting were evaluated on Alfisols and on deep and medium deep to shallow Vertisols. Relatively large plots (0.3 to 0.4 ha) were used for these comparisons because the relevant factors (runoff, erosion, drainage, operational requirements, etc.), do not express themselves adequately on small plots. Also, the recommended distance between contour bunds is taken as a guideline for appropriate plot size. Runoff and erosion were measured on only two of the four replicates. Visual observations of factors such as weed conditions, drainage, workability of the soil, plant-stand establishment, etc., were recorded.

On deep Vertisols (BW5 A) three cultivation treatments were compared - flat planting, narrow (75-cm) ridges, and a bed system with furrows at 150 cm. Slopes averaged 0.6 percent. Maize was planted during the rainy season, followed by a chickpea crop in the postrainy season. Because the rains terminated early, the seedbed was very dry when chickpea was planted and one irrigation of about 75 mm was applied on two replicates of each treatment. Data are summarized in Table 50.

Although there was more runoff from the broad ridges than from the narrow ridges, actual water conservation for crops was not increased because most runoff took place after the root profile was filled. Erosion quantities in all planting systems were acceptable; the high-intensity long-duration storms came after substantial plant cover had developed. Average maize yields on both types of ridged plots were superior to those from flat planting, although rather large variations between plot yields were observed - presumably caused by minor differences in soil type. Chickpea yields on broad ridges were superior to those obtained on narrow ridges or under flat planting, either with or without irrigation at planting time. These differences may be explained by the greater friability of the soil in broad ridges (which makes it easier to achieve adequate planting depth under dry conditions), operational problems in planting a second crop on narrow ridges, and difficulties in adequately irrigating flat-planted areas. The total gross value of the yields of maize and chickpea on broad ridges exceeded that obtained with flat planting by 770 and 900 Rs/ha, respectively, for the nonirrigated and irrigated systems. The increase on narrow ridges over flat planting was about half of that with broad ridges.

On medium deep and shallow Vertisols (BW8 B), identical land treatments were imposed; a maize/pigeonpea intercrop was grown. The results (Table 51) show that runoff and erosion were very small. Yields on broad ridges were superior to those under flat and narrow-ridged planting during both the rainy and postrainy season. Relatively low yields on narrow ridges are explained by the unsuitability of this treatment for intercropping systems, resulting in problems at planting time as well as in maintaining adequate weed control.

In conclusion, it appears-on the basis of yields obtained - that broad (150-cm) beds are an appropriate land-management technique on Vertisols. In addition it has been observed that preformed beds provide for faster and more uniform planting as well as a wider range of row spacings required by various crops (Fig 72). If early showers occur at planting time, the top of the bed dries more quickly, thus facilitating earlier planting. Germination of weeds has been found to be less in bed systems than in flat

Table 50. Effect of land management on runoff, erosion, and yield on deep Vertisob at ICRISAT Center, 1976-1977.

Land Treatment	Runoff	Erosion	Yields: Maize	Yields: Chickpea Nonirrigated	Yields: Chickpea Irrigated	Value[a] Nonirrigated	Value[a] Irrigated
	(mm)	(kg/ha)	(kg/ha)			(Rs/ha)	
Flat planting	141	240	2740	490	610	3170	3360
Narrow ridges	77	110	3240	450	650	3540	3860
Broad ridges	110	170	3170	740	940	3940	4260

[a]Total value of maize and chickpea.

Table 51. Effect of land management on runoff, erosion, and yield on medium deep Vertisols at ICRISAT Center, 1976-1977.

Land Treatment	Runoff	Erosion	Yields		Values[a]
			Maize	Pigeonpea	
	(mm)	(kg/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
Flat planting	14	10	2700	530	3 780
Narrow ridges	19	20	2470	480	3445
Broad ridges	17	20	3030	620	4310

[a]Total value of maize and pigeonpea.

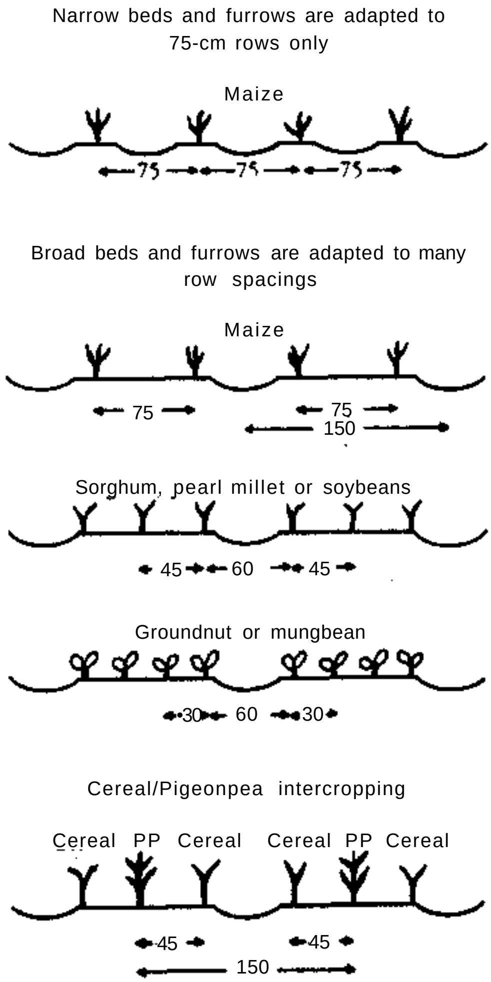


Figure 72. Cropping patterns and row spacings on 75- and 150-cm beds.

systems. Beds and furrows make application of supplemental water possible without further land treatment. Soil on the beds remains friable, facilitating postrainy season planting and land preparation after harvest of the second crop. Finally, with broad beds, crop land is not taken out of production for conservation purposes, as is the case with mechanical soil-protection structures such as bunds. The implementation and maintenance of beds from year to year is feasible with animal-drawn equipment. All fertilizers and plant residues are concentrated in the beds, thus increasing the productive potential of the soil in the plant zone.

Optimal Use of Supplemental Water

One drawback of "normal" irrigation in the SAT is that frequently only small areas of rainfed agriculture are replaced by irrigated agriculture oriented towards high-value crops which require large quantities of water. Total water resources in most semi-arid regions are too limited to envisage large-scale conventional irrigation. Therefore, ICRISAT's research on the utilization of available groundwater or collected surface runoff must aim at the development of viable technology providing for the supplemental use of limited water resources to stabilize and backstop rainfed agriculture.

In 1976-1977, the treatments designed for Alfisols and shallow to medium deep Vertisols during the rainy season-which were based on growth-stage sensitivity to drought stress and on rainfall probabilities-were not applied because the rainfall was adequate in quantity and distribution. This is the second time in succession that this situation has occurred. It appears necessary to explore the possibility of conducting supplemental-irrigation research on a multi-location basis during the rainy season. Through employment of cooperative programs, one can cover a wider range of rainfall conditions and obtain the necessary data more rapidly.

Cropping Systems

Intercropping has again received major attention this season. Another major effort involved more-detailed investigations in areas of particular promise, notably plant population and genotype evaluation. In the intercropping work, the aims are to identify the various aspects of population and spacing, and to assess their independent effects as well as their interrelationships. In the work with genotypes, the aims are to identify desirable genotype characteristics and to examine the problems of evaluating relatively large numbers of genotypes.

Intercropping performance is assessed by a "Land Equivalent Ratio" (LER) which is the relative area of sole crops required to produce the yield or yields obtained in intercropping. This permits direct comparison of crops with different yield levels and it can be used either for an individual crop or for the total of all crops. In the latter case, a total greater than unity indicates a yield advantage for intercropping, e.g. a LER of 1.2 indicates a yield advantage of 20 percent.

There has also been a further examination of the possibility of growing two successive crops on deep Vertisols where traditionally only a single postrainy season crop is grown. Again, both "sequential" sowing (seeding following harvest of the first crop), and "relay" sowing (seeding shortly before harvest of the first crop) have been examined.

The influence of legume/cereal intercropping on the development of pest populations has been examined with particular emphasis on the important pest, *Heliothis armigera* (Hubner). Information on the pest/parasite relationship in intercrops has also been obtained.

Plant Population and Spatial Arrangement in Intercropping

In maize/pigeonpea intercropping, response to total plant population (i.e., both crops combined) at various row-arrangement patterns was examined. It was found that to achieve maximum advantage from intercropping, the total population had to be higher than that for either sole crop alone. For either sole crop, the optimum population was six plants per square meter. At this level in intercropping, the yield advantage was 30 percent (Table 52). Although this is quite a substantial advantage, it was increased to 45 percent at a total population of nine plants/m^2. The data indicate that this might be further increased at even higher populations and this will be investigated further next season.

A particularly interesting aspect of this experiment was the effect of maize competition on the efficiency of the pigeonpea plant (Table 53). The absence of substantial reproductive growth of the pigeonpea until after maize harvest is considered to be due to maize competition. After maize harvest there was considerable compensation in reproductive growth, especially in number of pods per plant. Thus compared to the sole crop, the harvest index (HI) of the pigeonpea was substantially increased by intercropping. In the treatment with the highest proportion of maize the HI value was increased from 17.2 to 30.4 percent.

In the postrainy season, a new intercropping design permitted examination of population changes in either crop. Four chickpea populations were established in main plots and the population of a safflower intercrop was systematically changed within these. A 10-percent change between each safflower population gave a fourfold change in 15 steps. These population effects were distinguished from spatial arrangement effects by examining all population treatments at each of two row arrangements.

Table 52. Effects of plant population on grain yields and Land Equivalent Ratios (LER) in maize pigeonpea intercropping on Vertisol at ICRISAT Center, 1976-1977.

	Total plant population					
	$3/m^2$		$6/m^2$		9/m2	
	Yield	LER[a]	Yield	LER[a]	Yield	LER[a]
	(kg/ha)		(kg/ha)		(kg/ha)	
Sole maize	2 769	-	3 398	(1.0)	3 331	-
Sole pigeonpea	988	-	1035	(1.0)	954	-
Intercropping[b]						
Maize	1637	.48	2205	.65	2400	.71
Pigeonpea	780	.75	672	.65	768	.74
Total Land Equivalent Ratio (LER)		1.23		1.30		1.45
L.S.D. (0.05) between Total LER = 0.16						

[a]LER calculated from optimum sole crop yields (i.e., 6 plants/m^2).
[b]Mean of three row arrangements (See Table 53).

Table 53. Effect of different row arrangements on pigeonpea when intercropped with maize on Vertisols at ICRISAT Center, 1976-1977.

	Pigeonpea total dry matter	Pods per plant	Pigeonpea grain yield	Harvest Index
	(kg/ha)	(no/plant)	(kg/ha)	(%)
Sole pigeonpea	5 750	73.8	991	17.2
1 row pigeonpea/ 1 row maize	3 560	128.0	889	25.0
1 row pigeonpea/ 2 rows maize	2820	131.3	785	27.9
1 row pigeonpea/ 3 rows maize	1800	162.4	545	30.4
L.S.D. (0.05)	600	19.8	141	3.5

Safflower was the more competitive crop and it tended to reduce chickpea yield. But, except at very low populations, safflower was little affected by changes either in its own population or in that of chickpea. Thus the best intercropping combinations were those which maximized chickpea yield. These were moderately low safflower populations (to minimize safflower competition) combined with high chickpea populations (to maximize chickpea population response) (Fig 73). These combinations gave substantial yield advantages in alternate-row intercropping but

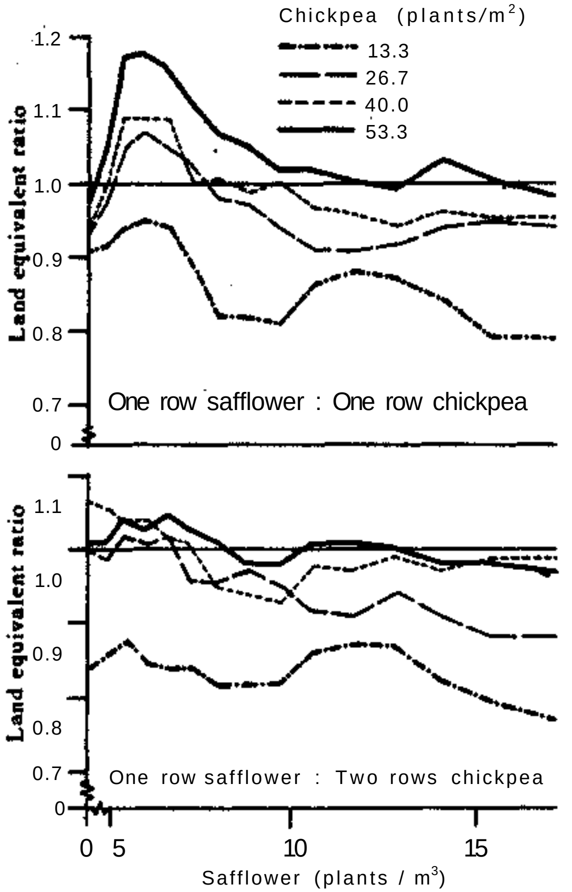


Figure 73. Population effects on saffower/ chickpea intercropping at two row arrangements on Vertisols at ICRISAT Center, 1976 (3-point moving average).

little or no advantage when the planting pattern was one row safflower to two rows chickpea. The advantages in alternate rows may have been partly due to a beneficial effect of shading on the chickpea, an effect which has been observed in the chickpea physiology research.

Genotype Evaluation

In cooperation with the pearl millet breeders, 40 pearl millet genotypes were subjected to initial intercrop screening with pigeonpea, Setaria, and sorghum. A large number of plant characters and yield determinants were measured on ail genotypes and these were correlated with intercropping performance. Unfortunately, yields of pigeonpea and Setaria were poor and no correlations with these crops were significant. With sorghum, the best correlations were with difference in height and difference in maturity. These effects were substantiated by a yield trial which examined all intercropping combinations of four pearl millet genotypes x four sorghum genotypes (Table 54). For two crops so similar, the advantages of intercropping were remarkably high. Nine of the 16 combinations gave advantages ranging from 10 to 32 percent. The two highest advantages were from the combinations of latest sorghum with earliest millet and earliest sorghum with latest millet. The third highest advantage was from the tallest sorghum with shortest millet. But other advantages could not be explained in terms of height and maturity differences. It seems likely that there are many other factors involved, so these crop combinations will be studied further next season.

Three-crop Intercropping

The effects of adding intercrops of Setaria (90 days), groundnut (134 days), or both to pigeonpea (184 days) were examined on both soil types (Table 55). The Setaria/pigeonpea combination gave a large advantage on both soils; groundnut gave a large advantage on Alfisols, but less on Vertisols. The three-crop combination gave larger advantages than the two-crop combination on Vertisols, suggesting that the different maturity periods of the three crops allowed some complementarity in terms of the use of growth resources over time. However, on Alfisols, the three-crop combinations gave smaller advantages than did the two-crop combinations. In view of the dry period during September, these data suggest that three-crop intercropping may be beneficial only if there is sufficient moisture to support all three crops.

Relay and Sequential Cropping

In 1975-1976, there was good evidence that a rainy season as well as a postrainy season crop

Table 54. **Land Equivalent Ratio and height and maturity differences of sorghum and pearl millet genotypes in intercropping on Alfisol at ICRISAT Center, 1976-1977.**

	Land Equivalent Ratio			Height	Maturity
Sorghum 4- Pearl millet	Sorghum	Millet	Total	(S>M cm)[a]	(S > M days)[a]
Y 75 + PHB 14	0.80	0.52	1.32	+ 59	+ 21
GE 196 + GAM 75	0.25	1.06	1.31	- 2	-14
Y 75 + GAM 75	0.69	0.55	1.24	+ 104	+ 9
CSH-6 + PHB 14	0.64	0.54	1.18	- 2	+ 8
GE 196 + Ex-Bornu	0.14	1.03	1.17	-87	- 9
Y 75 + Ex-Bornu	0.42	0.71	1.13	+ 19	+ 14
Y 75 + GAM 73	0.57	0.55	1.12	+ 102	+ 18
CSH-6 + Ex-Bornu	0.38	0.72	1.10	-42	+ 1
IS 9237 + Ex-Bornu	0.39	0.71	1.10	-25	+ 11
CSH-6 + GAM 75	0.53	0.53	1.06	-43	- 4
GE 196 + PHB 14	0.20	0.85	1.05	-47	- 2
IS 9237 + PHB 14	0.45	0.59	1.04	+ 15	+ 18
GE 196 + GAM 73	0.22	0.82	1.04	- 4	- 5
CSH-6 + GAM 73	0.48	0.51	0.99	+ 41	+ 5
IS 9237 + GAM 73	0.42	0.56	0.98	+ 58	+ 15
IS 9237 + GAM 75	0.35	0.61	0.96	+ 60	+ 6

[a] S > M refers to the amount the sorghum exceeds pearl millet in height (cm) or in maturity (days).

Table 55. **Yields and Land Equivalent Ratios of pigeonpea intercropped with Setaria and groundnut at ICRISAT Center, 1976-1977.**

	Pigeonpea		Setaria		Groundnut		Total
	Yield	LER	Yield	LER	Yield	LER	LER
	(kg/ha)		(kg/ha)		(kg/ha)		
Alfisol							
PSSS[a]	400	0.85	1860	0.75			1.60
PGGG	400	0.85			970	0.69	1.54
PSGS	350	0.74	1420	0.57	240	0.17	1.48
PSGGGS	270	0.58	970	0.39	380	0.27	1.24
Vertisol							
PSSS	700	0.57	1970	1.11			1.68
PGGG	1070	0.88			220	0.41	1.29
PSGS	810	0.66	1840	1.04	70	0.13	1.83
PSGGGS	630	0.52	1480	0.84	250	0.46	1.82

[a] P = pigeonpea, S - Setaria, and G = groundnut.
Distance between all intercropping rows was 37.5 cm.

could be grown on deep Vertisols, though traditional practice in India is to grow a postrainy season crop only. These investigations were continued by growing six postrainy season crops (i) after fallow and (ii) after a crop of maize grown on 75-cm ridges. There were three dates of sowing equivalent to 24, 12, and 0 days before maize grain harvest. At the two earlier dates, the treatments following maize were (i) relay sown into the full maize crop and (ii) relay sown after removal of alternate maize rows for greencobs; the last sowing date was essentially a sequential sowing after maize. (Due to abnormal drought conditions in September, a "come-up" irrigation was applied after the first planting.) These treatments also provided three "shade" comparisons: (i) no shade (after fallow), (ii) half shade (after harvest of greencobs), and (iii) full shade (under full maize crop).

Germination at the second time of sowing was poor until rain fell just after the third sowing; therefore there was little difference in terms of performance between these dates. It can be seen (Table 56) that the growing of a rainy season maize crop had little or no effect on the yield of the postrainy season crops. The half-shade treatment obtained by the greencob harvest appeared to have a small beneficial effect on the yield of safflower, sunflower, and cowpea. Pigeonpea and sorghum benefitted from earlier sowing, whereas chickpea and safflower benefitted from late sowing.

Monetary values of the different systems are summarized in Figure 74. For single cropping after fallow, the highest yield of the three sowing dates is taken. For sequential cropping after grain maize, the mean of the two latest sowing dates is taken because in practice they germinated at the same time. The "greencob" system gave the greatest returns because of the high

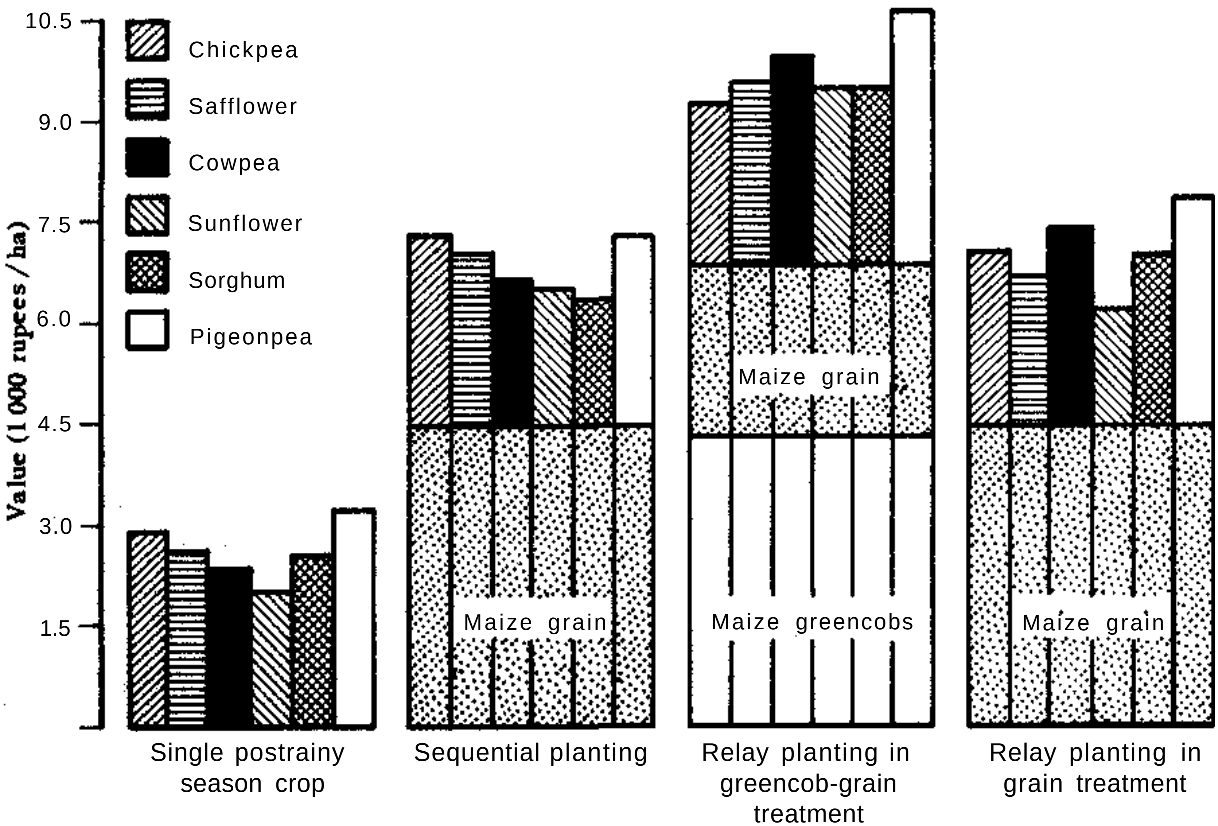


Figure 74. Monetary values of sequential and relay planting after maize.

Table 56. Relay and sequential sowing of postrainy season crops after maize compared to single cropping after fallow on Vertisol at ICRISAT Center, 1976–1977.

	Yield (maize grain)	Sowing time[a]	Yield of postrainy season (second) crop					
			Pigeonpea	Chickpea	Sorghum	Safflower	Sunflower	Cowpea
	(kg/ha)		(kg/ha)					
Rainy season treatment:								
1 Fallow		24	1 200	1 250	2 810	730	800	770
2 Fallow		12	920	1 830	2 210	990	680	650
3 Fallow		0	990	1 750	2 490	1 110	900	600
4 Maize greencobs and grain[b,c]	2 880	24	1 410	1 530	2 940	1 110	1 070	1 040
5 Maize greencobs and grain	2 880	12	980	1 810	1 570[d]	1 270	1 080	800
6 Maize greencobs and grain	2 880	0	880	1 600	1 660[d]	1 160	800	960
7 Maize grain	5 120	24	1 240	1 600	2 810	900	680	970
8 Maize grain	5 120	12	1 120	1 780	2 160	910	580	710
9 Maize grain	5 120	0	960	1 720	1 960	1 100	770	750
Rainy season maize management systems:								
1, 2, 3 Fallow		all	1 030	1 620	2 500	940	790	680
4, 5, 6 Maize green cobs and grain	2 880	all	1 090	1 640	2 060[d]	1 180	980	930
7, 8, 9 Maize grain	5 120	all	1 110	1 700	2 310	970	670	810
L.S.D. (0.05)			NS	NS	NS	210	220	180
Sowing dates:								
1, 4, 7 All		24	1 280	1 460	2 850	910	840	920
2, 5, 8 All		12	1 010	1 800	1 910	1 060	780	720
3, 6, 9 All		0	940	1 690	2 030	1 120	820	770
L.S.D. (0.05)			210	270	490	NS	NS	NS

[a] Sowing dates of postrainy season crops were 24, 12, and 0 days before maize grain harvest – 6 Oct, 18 Oct, and 30 Oct, respectively.
[b] In treatments 4, 5, and 6, every other row of maize (50 % of the area) was harvested for greencobs 24 days before the remaining rows (50 % of area) was harvested for maize grain.
[c] Greencob yield was 27 575 cobs/ha; this was in addition to 2 880 kg grain per ha.
[d] A few plots under these treatments were severely infested by the weed *Cynodon dactylon*.

value of greencobs; in practice, the feasibility of this system depends on the marketability of greencobs. After this system, two of the best systems were chickpea planted after maize and pigeonpea relay planted 24 days before maize harvest.

Cropping Systems Entomology

The influence of legume/cereal intercropping on the development of pest populations has been examined with particular emphasis on the important pest, *Heliothis armigera* (Hubner). This year information on the pest/parasite relationship in intercrops has also been obtained.

***Heliothis armigera* (Hubner).** *H. armigera* was recorded feeding on SO cultivated plant species and 51 weed species. The most significant "carry-over" hosts in the hot summer season are the weeds *Datura metel, Acanthospermum hispidum,* and *Gynandropsis gynandra.* However, out-of-season crops of tomato, cowpea, and maize grown under irrigation carried a large number of larvae-up to 156000 larvae/ha on cowpea in March. In January 103 000 larvae/ha were found on pigeonpea, while on chickpea in the same month up to 248000 larvae/ha were present. Generally, populations on all host plants were low from April to June.

Peak oviposition in *H. armigera* is generally associated with the flowering of its host plants. Detailed observations were carried out on moth behavior in cowpea and irrigation was noted to cause a considerable increase in the number of adults present in the crop.

Nineteen parasitoids of *H. armigera* have been recorded. Parasitism levels varied, depending on crop and season. Parasites were recorded in all months except June. Mermithids were important early in the season (Jul-Sep), Diptera in October and January, and Hymenoptera in most months but particularly in September-October and December-February. Overall parasite levels were far higher on crops which had not been sprayed (28 %) than on sprayed crops (10%) (Table 57). This was also true in other areas of Andhra Pradesh where parasitism rates of 1 to 3 percent were recorded in DDT-sprayed intercropped pigeonpea compared with 22 percent in one nonsprayed field. Egg parasites recovered were *Trichogramma confusum* Viggiani, and *Microchetonus curvimaculatus* Cameron. No virus particles were recovered from a number of diseased larvae submitted to the Boyce Thompson Institute. Studies on chickpea grown in 25 farmers' fields revealed high parasitism levels on *H. armigera* and this had a considerable influence on pod damage, which was generally low (up to 8 % pods damaged). Three farmers applied DDT at early podding stage but with no obvious benefit.

Insect relationships in intercropping. Techniques for assessing pest and pest-parasite ratios and yield losses in intercrops were devised using two cultivars of pigeonpea, HY-2 (semierect) and HY-3A (erect) in Alfisol and in deep Vertisol. The treatments were sole-crop pigeonpea (PP), pigeonpea intercropped in alternate rows with CSH-5 sorghum (PP/S), with HB 3 pearl millet (PP/PM), with H-1 Setaria (PP/St), and pigeonpea mixed with sorghum within rows (PP + S).

Several pod borers were recorded damaging pigeonpea, but the pod borer *H. armigera* was by far the most common species present and an obvious cause of yield loss. Damage by pod fly, *Melanagromyza obtusa* (Mall.), increased during the later stage, particularly on cv HY-3A.

Eggs laid and number of larvae of *H. armigera* were far lower on pigeonpea grown on the Alfisol than on the deep Vertisol, and a similar trend appeared in moth numbers trapped (Fig 75). Larval parasitism by Diptera was much higher than by Hymenoptera on pigeonpea, and levels declined as both cultivars approached maturity in both soil types.

No differences in levels of *M. obtusa* damage were observed between trials grown on the two soil types, but time played an important role. Cultivar HY-3A was more susceptible and heavily attacked. An increasing trend of pod shedding in cv HY-2 in Vertisol and cv HY-3A on Alfisol was observed. Up to 62 percent of shed pods were damaged, 56 percent by lepidopteran borers, 2 percent by pod fly, and 4 percent by a hymenopteran pest, *Taraostigmodes* sp.

Table 57. Larval parasitism on *Heliothis armigera* (Hubner) in sprayed versus pesticide-free areas, ICRISAT Center (Sep-Mar 1976-1977).

Parasites	Larval parasitism	
	Pesticide-free[a]	Sprayed area
	(%)	(%)
Diptera		
Eucarcelia (Carcelia) *illota* Curran	8.3	3.1
Goniopthalmus halli Mes.	9.9	1.4
Others (three species)	1.0	0.6
Total	19.2	5.1
Hymenoptera		
Diadegma sp.	5.3	4.1
Eriborus argenteopilosus Cameron	3.1	0.3
Campoletis chlorideae Uchida	0.6	0.8
Others (five species)	0.2	0.1
Total	9.2	5.3
Overall parasitism (%)	28.4	10.4
Larvae collected (total)	3828	7877

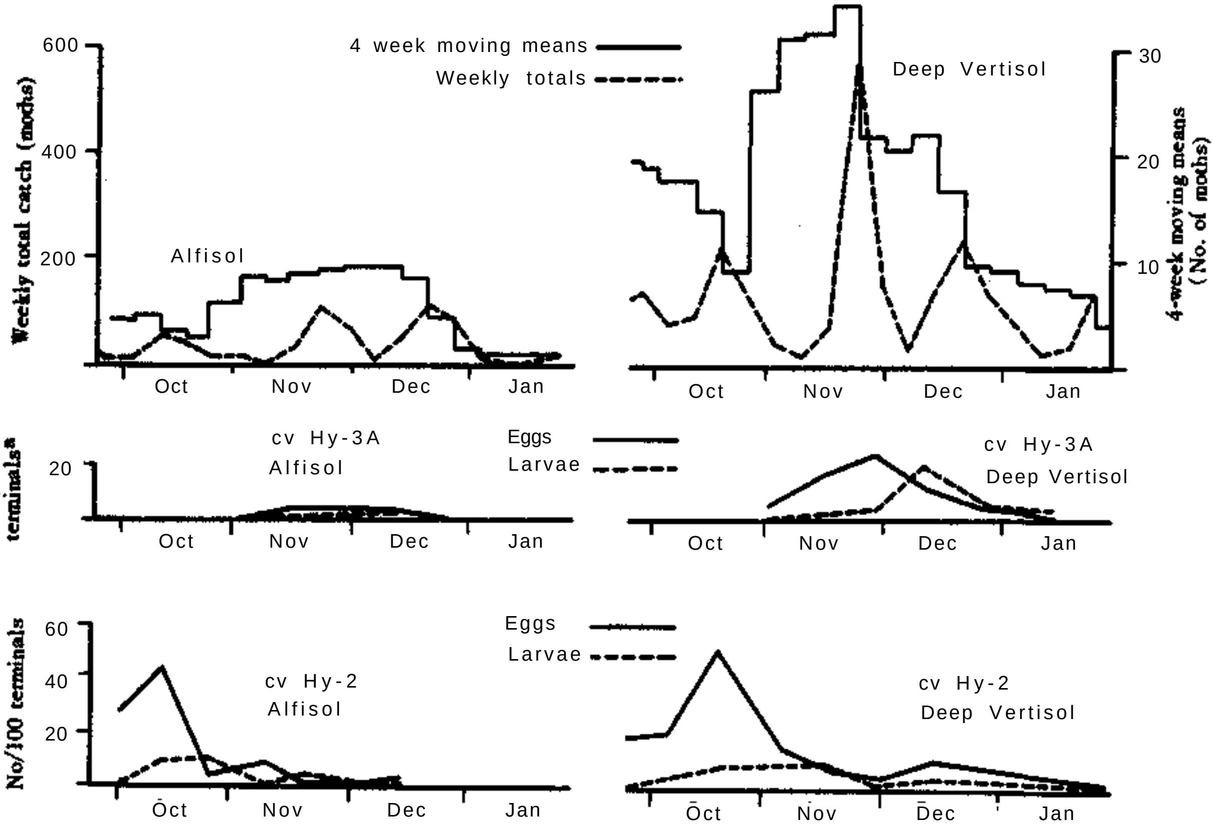
[a]Area BA-25 at ICRISAT Center has been set aside as a perpetual pesticide-free area.

The final yield-loss data were obtained using the actual weights of damaged and undamaged pods and seeds and calculating the potential yields if all pods had been undamaged. Loss in seed yield caused by insect pests was lowest in sole-drop blocks of cv HY-2 in Vertisol and of cv HY-3A in Alfisol (Table 58). Increased damage to pigeonpea in Vertisol resulted in reduced shelling percentages in both the cultivars.

The yield of both cultivars was higher on Alfisol in intercropped blocks but cv HY-2 in the sole-crop block yielded more on Vertisol (Table 58).

Crop proportion (pigeonpea/sorghum) studies. On sorghum (CSH-5) and pigeonpea (ICP-1) sown in various crop proportions in late June in Vertisol, the percentage larval parasitism on *H. armigera* on sorghum declined with the increase in plant population, but the levels were only significantly different ($P < 0.05$) during the peak parasite activity on pigeonpea (Table 59). Data from similar trials during 1975-1976 on both soil types revealed that fewer egg and larval numbers were present on blocks with fewer plants per ha. Pest numbers, pest-parasite ratios, and plant-density relationships will affect the efficiency of selection procedures for resistance to *H. armigera* in the pigeonpea screening program.

Pest monitoring on sorghum in intercrop/crop proportion trials. It was confirmed that shootfly, *Atherigona soccata* Rond., attack was more severe on later sowings. Damage levels were higher on sorghum grown on Alfisols with up to 43 percent compared with a maximum of 20



a. The terminal is distal 25-cm portion of the pigeonpea branch.

Figure 75. Heliothis armigera *(Hubner) eggs and larvae per 100 terminals on intercropped pigeonpea (cv HY-2 and HY-3A) and moths trapped at two locations, ICRISAT Center, 1976-1977.*

percent in Vertisols. This was associated with slow initial growth of seedlings in Alfisols. Heavier attacks were also obtained on sorghum due to slow growth in some Vertisol areas sown after unweeded fallow. *Orius* sp., a predatory bug, and earhead bugs, *Calocoris angustatus* Leth., were present in higher numbers on Alfisols than on Vertisols (S3 compared with 25 per 40 earheads and 16.5 compared with 3 per 40 earheads, respectively). Predatory spiders were found in greater numbers on sorghum earheads on Alfisols, while thrips were more numerous on Vertisols (21 compared with 15 per 40 heads).

Light-trap studies and insect fauna at ICRISAT Center. A third light trap at a Vertisol watershed was commissioned in April 1977. Three years of regular light-trap monitoring of more than 50 important pests of the SAT on legumes and cereals is revealing basic information on seasonal variations in pest species.

Four-week moving means during 1974-1977 for *H. armigera* moths recorded from Trap 1 are shown in Figure 76. The first and the third peaks were further displaced during this year, but the second appeared in the same week as observed during 1974-1975. A fourth peak at the end of April this year was from a summer cowpea crop at ICRISAT Center.

The most significant pests and beneficial fauna to date on the range of crops were authenticated. A list of parasites, predators, and hyperparasites, along with a detailed list of pests and insects, has been compiled.

Table 58. Pod numbers produced per 25 plants, yield, and percentage of insect-caused yield loss on intercropped pigeonpea (cv HY-2 and HY-3A) on Alfisol and Vertisol, ICRISAT Center, 1976-1977.

Treatment		HY-2[a]		HY-3A	
		Alfisol	Vertisol	Alfisol	Vertisol
PP/S[b]	Pods (no/25 plants)	930.2	710.8	582.7	525.8
	Yield (kg/ha)	320.2	169.6	175.7	84.4
	Yield loss (%)	19.7	35.1	43.9	43.0
PP/S[c]	Pods (no/25 plants)	790.7	426.6	707.2	455.0
	Yield (kg/ha)	336.5	120.3	279.2	69.9
	Yield loss (%)	23.2	39.6	41.3	51.1
PP/PM	Pods (no/25 plants)	1 045.0	765.6	837.5	424.4
	Yield (kg/ha)	302.2	219.3	375.0	94.6
	Yield loss (%)	18.0	23.9	38.9	54.6
PP/St	Pods (no/25 plants)	1 175.5	841.2	888.0	651.6
	Yield (kg/ha)	405.7	229.5	426.7	200.0
	Yield loss (%)	24.1	27.3	35.6	49.0
PP	Pods (no/25 plants)	1101.7	1257.8	1 277.0	677.2
	Yield (kg/ha)	317.2	489.5	634.5	193.8
	Yield loss (%)	20.7	22.6	31.0	55.0
L.S.D. (0.()5)					
	Pods (no/25 plants)	NS	NS	227.1	86.1
	Yield (kg/ha)	NS	NS	169.2	NS
	Yield loss (%)	3.8	9.0	NS	NS

[a] Inclusive of two pickings.
[b] PP = Pigeonpea, S = Sorghum, PM = Pearl Millet, St = Setaria.
[c] Sown mixed within rows.

Agronomy and Weed Science

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 the rainy season as far as possible into the postrainy season. Because of the great potential for increased production by intercropping and other double-cropping systems, additional emphasis has been placed upon basic studies (reported in a separate section under the Cropping Systems subprogram) in this field. Agronomic research reported here involved preliminary studies on row direction and lodging, weed-management research, and a continuation of the "Steps in Improved Technology" experiments.

In the SAT, many weed-control problems remain unsolved due to limited weed research on crops and cropping systems. At ICRISAT Center, the major approach to weed management is through habitat management, and research efforts are being oriented to obtain more basic information on the crop-weed balance. Weed research on individual crops was designed mainly to determine the competitiveness with weeds of distinctly different cultivars of the major crops and to study the tolerance of these cultivars to some selected herbicides.

Effect of Row Direction and Artificial Lodging Upon Pigeonpea Yields

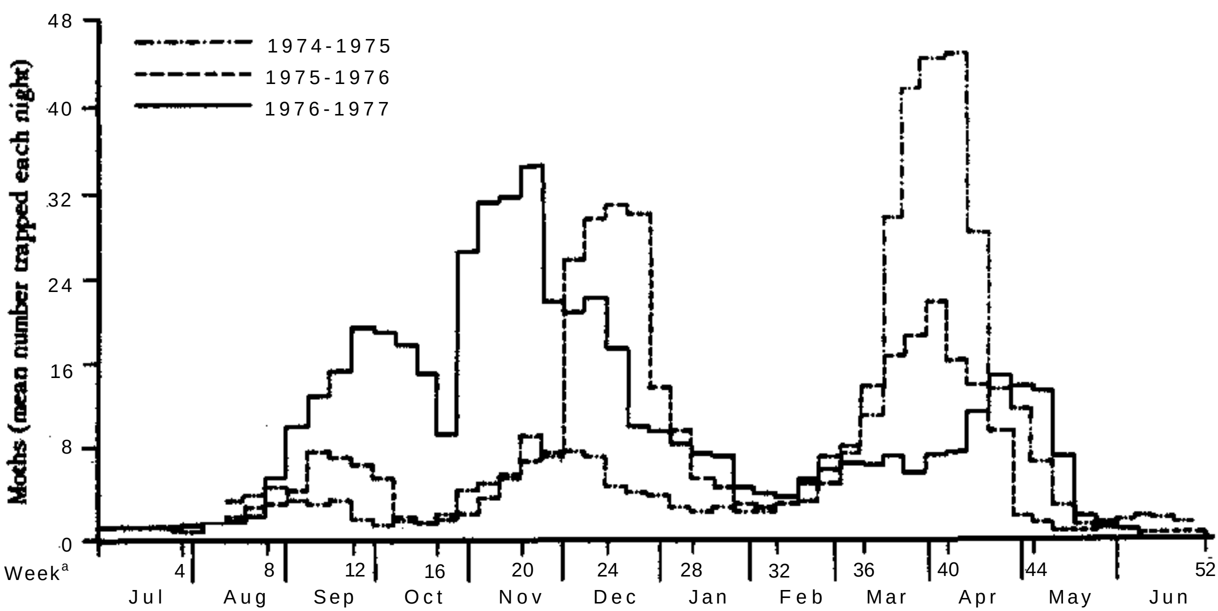
A preliminary trial was established to study the effect of row direction (north-south vs. east-west) of two cereals and pigeonpea alone and in intercropping systems.

Pigeonpea yields in the north-south direction were significantly higher than those in the east-west direction on both Alfisols and Vertisols.

Table 59. Parasitism levels on *Hetiothis armigera* (Hubner) from sorghum (CSH-5) and pigeonpea (ICP-1) grown in various crop proportions in deep Vertisol, ICRISAT Center, 1976-1977.

Plant population (Pigeonpea/Sorghum)	Parasitism				
	Sorghum	Pigeonpea			
	Mid-Sep	Late Nov	Mid-Dec	Early Jan[a]	Early Feb
(1000/ha)	(%)				
32.0:85.5	40.5	9.5	32.0	34.5	39.4
15.0:128.5	37.9	9.5	37.0	50.5	34.4
11.5:145.0	31.5	8.0	39.0	51.0	17.9
8.0:150.0	26.9	15.0	53.0	59.0	30.2
L.S.D. (0.05)	NS	NS	NS	7.3	NS

[a]Peak activity of parasites observed.



[a]Beginning 1 Jul.

Figure 76. Catch of Heliothis armigera *(Hubner) from August 1974 through May 1977 in Trap No. 1 (at Crap Improvement Building), ICRISAT Center. Plotted as 4-week moving means.*

Plants artificially lodged appeared to increase the flush of new branches at the nodes above the bent area; however, there was no significant effect upon pigeonpea grain yield in either soil.

Setaria planted in the north-south row direction in the pigeonpea intercropping system gave significantly higher yields than plantings in the east-west row direction. In the maize/pigeonpea intercropping system, the maize yield trend was similar, but the differences were not significant. These results are in agreement with results on wheat (Santhisegaram 1962) and on maize (Dungan et al. 1955).

Evaluation of Genotypes of Low-growing Legumes in a Pigeonpea/Cereal Intercrop System

Several genotypes of low-growing legumes were tested as a third crop in a pigeonpea/cereal intercrop system. These low-growing legumes were planted on broad beds in between the pigeonpea and cereal rows, thus giving five rows of crops for 150 cm of space.

In the Alfisols the introduction of mung beans, cowpeas, black gram, or groundnut had no significant effect upon the grain yield of the rapid-growing upright Setaria. There was, however, a small but significant depression in pigeonpea grain yield when low-growing legumes were introduced.

In spite of the slight pigeonpea yield reduction, the total monetary value was greater in the three-crop intercrop systems than in the two-crop (pigeonpea/Setaria) system. There were, however, large differences in the genotypes used, especially in cowpeas and groundnuts. The best cowpea (1152) and groundnut (Robut 33-1) cultivars in the three-crop combinations produced total monetary values of Rs 5230/ha, about 50 percent above that produced in two-crop systems.

The large differences in yield between genotypes of low-growing legumes and the differential effect upon the yield of the other two intercrops needs further research to evaluate genotypes and identify crop systems which are mutually compatible.

Steps Towards Improved Technology

In the development and implementation of improved technology, there are many facets or "steps" involved. If one attempted to research each of the individual phases in combination, the total number of combinations would become unmanageably large; also, the effects of many individual facets have been investigated previously. For convenience the many steps were grouped into the following four phases: Variety, Fertilization, Soil and Crop Management, and Supplemental Water (where needed).

Sorghum on Alfisols. In 1975, a sorghum experiment involving comparisons of traditional vs. improved technology on an Alfisol was initiated. This experiment was repeated in 1976 with a slight modification in treatments. During the main crop (rainy) season the rainfall distribution was adequate and fairly uniform; supplemental water was not required. Thus, Treatments 9 and 10 were considered as additional replications of Treatments 4 and 8, respectively, and only the first three phases can be considered in interpretation of the main crop yields; however, Treatments 9 and 10 were considered separately in the ratoon crop (Table 60). There was a significant response to improved fertilization. Improved variety and improved management as single factors showed an upward trend, but this was not significant. Sorghum yield in the 1975 experiment showed the same trends. In comparing yields of improved vs. traditional levels for these three factors applied individually, the sum of the increase was 1489 kg/ha; however, when all three factors were combined (Treatment 8), the increase was 3092 kg/ha-(Table 60).

Figure 77 shows the yield increases of improved over traditional technology from the application of the three steps (Variety, Fertilization, and Soil and Crop Management) singly and combined. Yield increases from the three steps combined was double that of the sum of the increase due to the same three steps applied singly, thus illustrating the large synergistic effect of the three steps when applied together in a system. There was a slight synergistic effect when

Table 60. Effect of traditional vs improved levels of four "Steps in Improved Technology" upon sorghum grain and fodder yields on an Alfisol at ICRISAT Center, 1976.

Treatment	Var.	Fert.	S & C Mang.	Supp. Water	Grain yield: Main crop	Grain yield: Ratoon crop	Grain yield: Total	Fodder yield: Main crop	Fodder yield: Ratoon crop	Fodder yield: Total	Net Benefit[d,e]
				(cm)	(kg/ha)			(kg/ha)			(Rs/ha)
1	Trad[a]	Trad	Trad	0	333	187	520	4250	752	5000	−271
2	Trad	Trad	Impr[b]	0	615	328	940	3230	614	3840	−254
3	Trad	Impr	Trad	0	1238	216	1450	5120	564	5680	447
4	Trad	Impr	Impr	0	1930	343	2270	6200	739	6940	1159
5	Impr	Trad	Trad	0	635	199	830	1770	517	2290	−462
6	Impr	Trad	Impr	0	1067	236	1300	2040	521	2560	−335
7	Impr	Impr	Trad	0	1754	173	1920	3060	367	3430	180
8	Impr	Impr	Impr	0	3425	359	3780	3590	437	4030	1389
9	Trad	Impr	Impr	10[c]	1930	723	2650	6200	1481	7680	567
10	Impr	Impr	Impr	10[c]	3425	904	4330	3590	889	4480	951
L.S.D. (0.05)					493	193	591	890	258	946	–

[a] Trad = Traditional: Variety—PJ8K; Fertilization—50 cartloads (15 ton/ha) farmyard manure in 1975 (none in 1976). Soil and crop management – simulates the present traditional farmer practice with bullocks and desi implements; fertilizer broadcast; seed sown with three-row desi drill (called Tipon) with 30 cm between rows; minimum insect control, if needed.

[b] Impr = Improved: Variety—CSH-6; Fertilization—75 kg/ha 18-46-0 at planting plus 67 kg N/ha topdressed. Soil and crop management – all tillage, planting, and cultivation with improved animal-drawn implements. Fertilizer banded and seeds planted in three rows 45 cm apart on broad ridges 150 cm apart. Atrazine at 0.75 kg/ha applied. Minimum insect control, if needed.

[c] Water was not applied to the main (rainy season) crop; 5 cm of water was applied to the stubble just after harvest of the main crop and 5 cm at flowering stage of the ratoon crop.

[d] Net benefit = gross income – all costs.

[e] Market prices: Local sorghum PJ8K grain, Rs 85/100 kg; CSH-6 grain, Rs 68/100 kg; local PJ8K sorghum fodder, Rs 7/100 kg; CSH-6 fodder, Rs 5/100 kg.

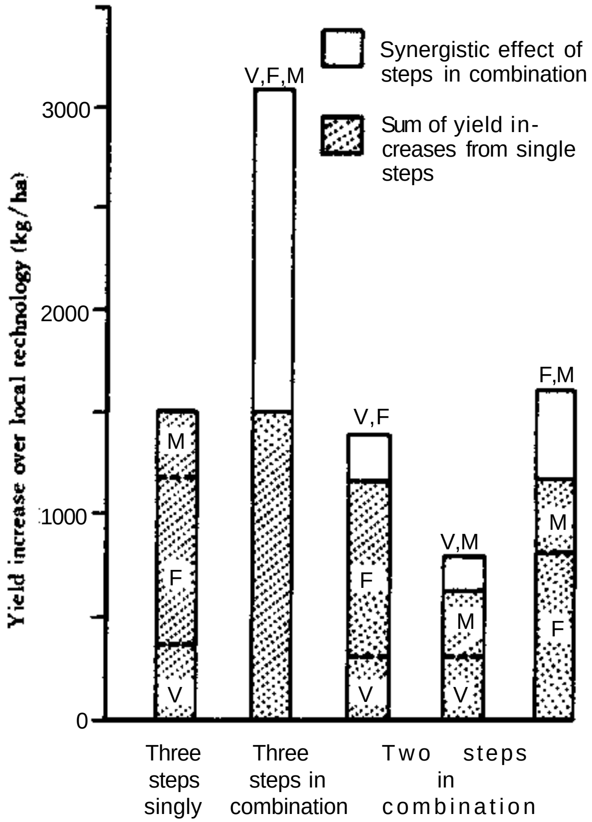


Figure 77. Sorghum yield increases from improved variety (V), fertilization (F), and soil and crop management (M) singly and in combination over traditional technology, ICRISAT Center, 1976.

any two of the factors were combined; however, the magnitude of this effect was far less. Similar synergistic effects were observed in maize yields in North Carolina (Krantz and Chandler 1975), and in wheat yields in India (Krantz et al. 197S) when all major "steps" were combined in a production system.

Yields of the ratoon crop were very low compared to that of the main crop, due to poor ratoonability and heavy attack of shoot fly. Total yields and net benefits are given for ratoon crop as Well as the main crop (Table 60). However, no attempt can be made to make either agronomic or economic interpretation of treatment effects upon the ratoon crop because of the poor ratoonability. In cooperation with the breeders it is planned to screen a large number of genotypes for ratoonability. The factors affecting ratoonability are also being investigated so as to capitalize on this method of double-cropping. As soon as good ratoonability can be achieved, treatment effects can be reliably interpreted and proper conclusions drawn.

The sorghum fodder yield of PJ8K was nearly double that of CSH-6. In contrast, the harvest index of the PJ8K variety was very low (7 to 24) compared to CSH-6 which ranged from 26 to 49.

Maize/pigeonpea intercrop in Verttsols. The treatments and yields of maize and pigeonpea in a Vertisol are shown in Table 61. No water was applied to the maize crop or the main pigeonpea crop and Treatments 9 and 10 were considered as additional replications of 4 and 8, respectively. As in the case of sorghum, maize yields were significantly increased due to improved fertilization, but improved variety or improved soil and crop management as a single factor did not increase yields significantly. However, with improved fertilization, the improved maize variety gave a highly significant response to management. These results again demonstrate the positive synergistic effect of one improved practice upon another.

In the case of pigeonpea, however, the story is quite different. Relatively little synergistic effect can be observed. This is believed to be due to the fact that the improved variety was not responsive to fertilizer and was not appreciably better than the traditional variety. Also the general yield level of this and all other pigeonpea experiments at ICRISAT Center was much lower in 1976 than in 1975, probably because of the September and October drought. The drought occurred during the critical flowering period after the removal of the competing cereal intercrop. However, improved soil and crop management, which included closer row spacing on pigeonpea, gave consistent and significant increases. In both varieties, there was also a significant yield increase in the pigeonpea ratoon crop due to a 5-cm water application immediately after harvest of the main crop. Since this is the first season in

Table 61. Effect of traditional vs. improved levels of four "Steps in Improved Technology" upon maize grain and fodder yields, pigeonpea main and ratoon crop grain yields, and value of grain, on a Vertisol at ICRISAT Center, 1976–1977.

Treatment	Var.	Fert.	S & C Mang.	Supp. Water	Maize Grain	Maize Fodder	Pigeonpea Main crop	Pigeonpea Ratoon crop	Pigeonpea Total	Net benefit[d,e]
				(cm)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
1	Trad[a]	Trad	Trad	0	450	2 290	310	10	320	−181
2	Trad	Trad	Impr[b]	0	660	1 450	552	62	614	502
3	Trad	Impr	Trad	0	1 900	3 220	353	99	452	1 050
4	Trad	Impr	Impr	0	2 610	3 355	505	67	572	1 841
5	Impr	Trad	Trad	0	630	2 990	417	82	499	534
6	Impr	Trad	Impr	0	960	2 470	586	53	639	900
7	Impr	Impr	Trad	0	2 220	3 780	445	95	540	1 560
8	Impr	Impr	Impr	0	3 470	4 460	501	103	604	2 665
9	Trad	Impr	Impr	5[c]	2 610	3 355	505	223	728	1 908
10	Impr	Impr	Impr	5	3 470	4 460	501	336	837	2 933
L.S.D. (0.05)					474	1 232	166	131	218	–

[a] Trad = Traditional: Varieties – maize short duration, traditional; pigeonpea, traditional. Fertilization – 10 ton/ha FYM in 1976. Soil and crop management – simulates the present traditional farmer practice with bullocks and desi implements; fertilizer broadcast; seeding with three-row desi drill (called Tipon) with 30 cm between rows; three rows of maize to one row of pigeonpea; minimum insect control, if needed.

[b] Impr = Improved: Varieties – maize, SB-23; pigeonpea, ICP-1; Fertilization – 75 kg/ha 18-46-0 at planting plus 67 kg N/ha topdressed. Soil and crop management – all tillage, planting, and cultivation with improved animal-drawn implements. Fertilizers banded and seed sown with one row of pigeonpea in center of ridge and a row of maize 45 cm to each side on broad ridges 150 cm apart. Alachlor at 0.75 kg/ha applied. Minimum insect control, if needed.

[c] Water was not applied to maize intercrop or pigeonpea main crop; 5 cm of supplemental water was applied at harvest of pigeonpea for the ratoon crop.

[d] Net benefit = gross income – all costs.

[e] Market prices: Maize, traditional, Rs 85/100 kg; SB-23, Rs 83/100 kg; Pigeonpea, traditional, Rs 190/100 kg; ICP-1, Rs 210/100 kg. Value of fodder not calculated.

which ratooning of pigeonpea has been tried, more research is needed before attempting conclusions.

Economic analysis of sorghum and maize/ pigeonpea intercrops. In the economic analysis, we considered total costs of input and the total value, including sorghum fodder. In the sorghum trial on Alfisols, the net benefit was by far the highest with Treatment 8. The next highest benefit was recorded for Treatment 4, showing that the traditional variety also responded reasonably well to improved management and fertilization. In all treatments with traditional FYM fertilization, the net benefits were negative (Table 60).

The highest rate of return in the maize/pigeonpea intercrop was for Treatment 8 (Fig 78).[8] The net benefits were highest for Treatments 8 and 10. Traditional methods (Treatment 1) showed negative net benefits and rates of return, while all the other treatments showed a positive rate of return (Table 61; Fig 78).

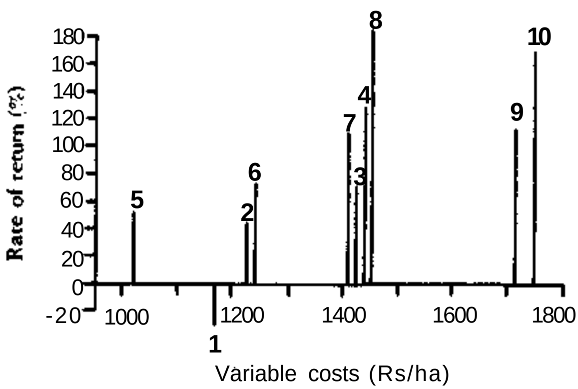


Figure 78. Returns from various steps in improved technology with a maize/ pigeonpea intercrop on a Vertisol at ICRISAT Center, 1976-1977. Treatment numbers (top of bar) are explained in Table 61.

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[8]Costs recorded for an application of 10 cm/ha is Rs 590, which equate Rs 5900/ha-m or about $70/acre-foot. Tank technology and water application research is under way to find lower-cost methods of providing supplemental irrigation.

Weed management in "Steps in Improved Technology" trial. Weed growth early in the rainy season is very rapid and if weeds are not removed on time, serious yield reductions can result. In Alfisols, which dry rapidly after a rain, hand weeding can be easily achieved. However, in Vertisols one may face serious problems when frequent rains while crops are in the seedling stage prevent the control of weeds by cultural or hand-weeding methods. During the past season, the improved technology treatments received a minimal amount of herbicides which was very helpful in reducing weed competition in the early stage. This was particularly true on the Vertisols, where with traditional management the average number of woman days/ha for hand weeding was 48. With improved management, where alachlor was used at the rate of 0.75 kg/ha and where effective cultivation was possible in the broad bed and furrow system, only 10 woman days per hectare were needed. Thus, the hand weeding cost/ha was Rs 171/ha more in the traditional than in the improved management. In the Alfisols, the total of two hand weedings required 30 and 56 woman days/ha for improved and traditional management, respectively; hand weeding costs in traditional and improved treatments were Rs 252 and 135 per ha, respectively.

Further investigations on Vertisols are under way to try to develop an effective low-cost means of controlling weeds in the early stages under the wide range of rainfall conditions which occurs from year to year.

Yield comparisons: random samples vs. entire plot. In the maize/pigeonpea intercrop experiment on Vertisols, grain yields were determined by two methods-random selection of four sub samples (1.5 by 8 m) vs. harvest of the entire plot. Although there was some variation between replicates, within given treatments the two procedures correlated very closely. The average yield of all treatments determined by the random-sample procedure was 44 kg/ha higher than the yield obtained from harvesting the entire plot. This represents a difference of 2.4 percent. This, along with the information obtained by comparing the two harvest systems in several watersheds, gives confidence in the random-sampling procedure.

Weed-management Research

Intercropping. To investigate the influence of intercropping different crops on the trends in weed infestation, and to determine the nature and extent of weed problems in various pigeonpea-based intercropping systems, two field trials were conducted. Intercrops of cowpea and maize suppressed weeds in the early stages to the greatest extent, followed by mung, sorghum, and groundnuts. Weed infestation on both soil types was about the same in the early part of the season, but late-season weeds yielded two to four times higher weed weights in Vertisols than in Alfisols (Fig 79). The effect of intercrops on weed growth was perceptible even by the time of first hand weeding at 25 days. Though cowpea efficiently suppressed weeds in the early stages, weeds reappeared after the harvest. Systems with

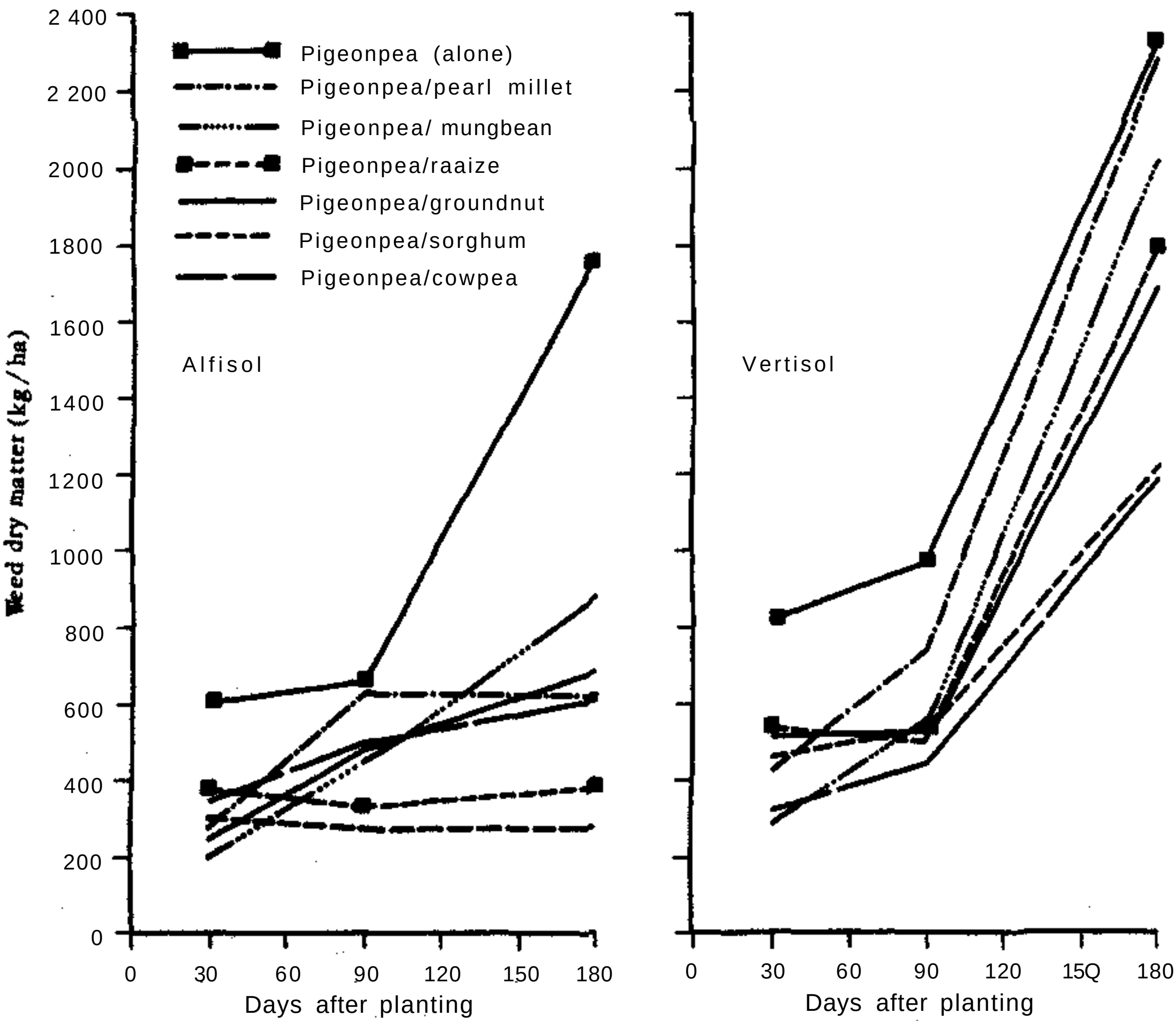

Figure79. Weed growth in pigeonpea-based intercrop systems on Alfisols and Vertisols, ICRISAT Center, 1976-1977.

maize and sorghum as intercrops recorded less weed growth at the final harvest of pigeonpea.

Preliminary weed observations recorded from other agronomic intercropping trials indicated that cultural and biological factors like plant-population pressure, crop species, and genotypes affect the crop-weed balance in intercropping. Increase in plant-population pressure resulted in a significant reduction in weed infestation, and spreading types of pigeonpea suppressed weed growth to a greater extent than did the compact type.

Even though intercropping can be a potential biological tool for management of weeds, the system by itself does not completely avoid weeds. Therefore, direct weed-control studies were also conducted to evaluate different herbicides on sorghum/pigeonpea intercrops. In general, triazine herbicides like ametryne, prometryne, and terbutryne performed well and were safe for both pigeonpea and sorghum (Table 62). The performance of fluchloralin was excellent on pigeonpea but was phytotoxic to sorghum, while atrazine was quite safe on sorghum but toxic to pigeonpea. Further weed-management studies on intercropping will be conducted to investigate means of manipulating various physical, biological, and cultural factors.

Double-cropping. In a trial to determine the comparative efficacy of alachlor and atrazine applied to dry and wet soils (after rains), there was no significant difference in yields of sorghum and maize. The dry applications were as efficient as wet applications, even though weed-control efficiency usually tends to be greater in case of wet applications. It was concluded that either herbicide may be applied either dry or after rains, depending upon convenience, without altering its efficacy. This information has practical implications in that the herbicides may be applied immediately after dry planting before the rains for rainy season cropping in deep Vertisols of the SAT.

Table 62. Efficacy of different preemergence herbicides in CSH-5 sorghum intercropped with HY-3A pigeonpea on Alflsols, at ICRISAT Center, 1976-1977.

Treatments	Rate	Sorghum yield (grain)	Sorghum yield (% of weed-free check)	Pigeonpea yield (grain)	Pigeonpea yield (% of weed-free check)	Weed dry matter at harvest: Sorghum	Weed dry matter at harvest: Pigeonpea
	(kg/ha)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)
Dinitramine	0.5	1400	39	290	85	1450	840
Devrinol	1.0	1870	52	270	79	1350	1310
Proraetryne	1.5	2 790	78	320	94	510	810
Terbutryne	1.5	2910	81	270	79	570	1140
Ametryne	1.5	3090	86	310	91	690	720
Destun	1.5	810	23	190	56	2320	1790
Fluchloralin	1.5	1000	28	360	106	1710	1140
Atrazine	1.5	2500	70	- -		2720	1160
Alachlor	2.0	1860	52	180	53	1120	1270
Weed free	-	3 590	100	340	100	-	-
Weedy check	-	1190	33	160	47	3650	2200
L.S.D. (0.05)	-	660	-	140		-	-

A trial was conducted to explore the possibilities of employing the minimum- and zero-tillage concept to reduce the time lag between crops and to conserve soil moisture, both of which are very critical for the optimum growth of a postrainy season crop of chickpea. The maximum yields of chickpea were obtained in the following three treatments: optimum tillage and hand weeding, paraquat and prometryne with no cultivation, and paraquat and three cultivations (Table 63).

Individual crops. Major emphasis is being directed to determine the competitiveness with weeds and herbicide tolerance of different cultivars of sorghum, pigeonpea, pearl millet, chickpea, and groundnut. Field trials involving many cultivars of these crops conducted during the 1976-1977 seasons indicated that crop cultivars differ in their tolerance to a given herbicide and also vary in their weed competitive ability. As this "intra specific differential response" may be related to environmental conditions, continuing research on this problem is planned before drawing definite conclusions. Similarly, experiments are also being continued to determine the ability of different crop cultivars to suppress weeds and their ability to grow well in spite of them. In groundnut, spreading and semispreading cultivars were significantly more competitive with weeds than was the bunch type. In pearl millet, tall and profusely tillering cultivars compete with weeds more efficiently than dwarf and poor tillering types. In sorghum, plant height and initial seedling vigor were the characters identified as responsible for weed competitive ability.

Table 63. Crop stubble and postrainy season weed management for chickpea on Vertisols at ICRISAT Center, 1976-1977.

Treatments	Yield	Weed dry matter at harvest
	(kg/ha)	(kg/ha)
1 Hand weeding + three cultivations	1060	300
2 Three cultivations	790	1070
3 Paraquat (1.0 kg/ha) + three cultivations	1030	790
4 One minimum cultivation + paraquat (1.0 kg/ha)	530	980
5 Paraquat (1.0 kg/ha) + prometryne (0.75 kg/ha) and no cultivation	1030	650
L.S.D.(0.05)	240	420

Herbicide screening. To determine the crop tolerance and weed-control activity of some selected herbicides, two herbicide-screening trials were conducted. Visual evaluation of crop injury and weed control from preemergence applications of herbicides recorded on sorghum, pearl millet, pigeonpea, chickpea, and groundnut are as follows: On sorghum, atrazine (1 kg/ha), prometryne (1.5 kg/ha), ametryne (1.5 kg/ha), terbutryne (1.5 kg/ha), and Tribunil (2.0 kg/ha) showed promise. Among the herbicides tested on pearl millet, only atrazine (0.5 kg/ha) and Tribunil (1 kg/ha) were found safe on the crop. Nitrofen (2 kg/ha), dinitramine (0.5 kg/ha), prometryne (1.0 kg/ha), ametryne (1.0 kg/ha), terbutryne (1.0 kg/ha), Modown (2.0 kg/ha), and Tribunil (2.0 kg/ha) were all found to be effective on pigeonpea. Among the herbicides evaluated on groundnut, dinitramine (0.5 kg/ha), alachlor (2.0 kg/ha), nitrofen (2.0 kg/ha), Prefar (4.01/ha), and devrinol (4 1/ha) proved promising. On chickpea, nitrofen (2.0 kg/ha), alachlor (2.0 kg/ha), dinitramine (0.5 kg/ha), Prefar (4 1/ha), prometryne (1.0 kg/ha), ametryne (1.0 kg/ha), and terbutryne (1.0 kg/ha), were found to be effective.

Weeds and weeding systems survey. In a few selected villages representative of the Indian SAT, surveys were made in collaboration with ICRISAT economists to observe weed problems, weeding systems, and the extent to which the farmers understand their weed problems. The existing methods of weed control are hand weeding with a small hoe and intercultivating with the traditional blade harrow or "Guntaka." The weed control activities of farmers of Mahbubnagar and Akola villages is clearly related to the quality of the resource base. The better the growth environment for the crops and weeds, the better the weed control. On the farms where weed management was not satisfactory, the major weeds found were *Cynodon, Cyperus, Desmodium, Digitaria, Echinochloa, Amaranthus, Celosia, Corchorus, Crotalaria,* and *Ipomoea.*

Looking Ahead in the Farming Systems Subprograms

Agroclimatology. Correlation of crop yields to weather conditions at a network of bench-mark SAT locations and determination of transferability of agroproduction technology among different areas will be attempted. Characterization of crop moisture availability in order to delineate homogeneous areas in the SAT is also being undertaken.

Activities during the initial phases of this work will include (i) establishing contacts for development of a meteorological data bank for locations of interest in the SAT; (ii) conducting agricultural climatic characterization studies for selected locations of Africa, Latin America, and India; and (iii) determining relationships between crop production and environmental factors.

Hydrology. Collection of hydrological data on alternative resource-management systems will continue at ICRISAT Center as well as in the cooperative programs. Work on refinement of sediment samplers-to improve accuracy and reliability-will continue. Data analyses will be computerized, and simulation of the runoff process will be attempted in cooperation with other research organizations.

Soil physics. Field studies of profile-water recharge and use will be conducted and detailed water balances for different periods of time will be computed for crops grown on Vertisols and Alfisols during the rainy and postrainy seasons. In cooperation with ICRISAT's physiologists and climatologists, a more-complete quantification of crop development, moisture stress, energy balances, and phasic root development will be used together with data on profile-water dynamics to evaluate a water-use and -yield model suitable for the soil-crop-atmosphere continuum at ICRISAT Center.

Soil fertility and chemistry. The long-term phosphate rock experiment will be continued. More experiments for the study of response of sorghum to N in an intercrop situation and pearl millet/groundnut intercrop responses to N and P are planned. Monthly sampling for determination of nutrient status will continue.

Farm power and equipment. Ongoing projects will be continued, with emphasis on adaptation of available farm machinery and development and testing of additional equipment needed to implement improved farming systems. Special emphasis will be given to adaptation of simple low-cost planting units which can sow successfully on Vertisols and Alfisols under a wide range of moisture conditions.

In multicropping situations in the SAT, the first crop is frequently harvested during the end of the rainy season. Thus, considerable drying may be required to bring the grain moisture content to a safe level for storage. Two approaches to this problem will be studied —

(i) Maize will be stored on the ear and then shelled after it is dry. Open-sided cribs, through which air may pass freely, will be built for storing the maize ears.

(ii) A solar grain dryer, using a flat-plate collector to heat air by solar energy, is being designed. The prototype will be used to dry, on an experimental basis, sorghum and millet grain during the late rainy season.

Land and water management. Present projects will be continued in order to improve methodology and to provide additional data on land-management and supplemental-water-utilization techniques. Research on improved practices will be initiated at several locations in India in addition to that at ICRISAT Center, and similar activities may be initiated at SAT locations in West Africa. Investigations (in cooperation with ICRISAT economists) of the water balances and water-use efficiencies in existing small- and medium-scale runoff collection facilities in Indian villages have begun; the objectives of these studies is to develop procedures that will provide a more effective use of available water. The possibility of involving other research institutions in this phase of the program is being explored.

Cropping systems. In the intercropping work, it is intended to put considerable emphasis on detailed study of growth and resource use in combinations of proven advantages, with the hope that ways in which yield advantages are achieved may be identified and improved. Detailed work on plant-population effects will continue, and genotype studies will be increased, hopefully to include all the ICRISAT crops. In the sequential and relay cropping studies, comparisons of maize and sorghum as rainy season crops will continue; postrainy season crops will be limited to chickpea, pigeonpea, and sorghum. Sorghum genotypes will be screened for ratoonability.

In cropping systems entomology, larger plots will be used to provide a more-realistic "field" situation that will permit regular sampling without seriously affecting population levels. Pest-parasite surveys in farmers' fields will be expanded. With the indications that some insecticide sprays may still be needed in intercropping situations, a prime objective of this phase of our work will be development of integrated pest-management systems. Importance of plant type, plant populations, and spacing will be further studied.

Collaboration with organizations-such as COPR, Boyce Thompson Institute, and CIBC - on the possibility of biological and viral control of *Heliothis* is being discussed and a survey of biological and microbiological agents on this insect in India is planned for the coming season. Plans for establishing a trap grid throughout the subcontinent so as to study migratory behavior of *H. armigera* in India will hopefully mature.

Agronomy and weed science. Further studies to determine the effects of different crop combinations, sequences, geometries, and genotypes, along with other physical, biological, and cultural factors on weed growth are planned. In the crop-oriented weed research, the major emphasis will be to determine growth characteristics responsible for weed competitiveness and to study the differential tolerance of different cultivars of ICRISAT crops to commonly used herbicides. In addition to the field trials at ICRISAT Center, observations in a few selected villages are planned to measure the success of farmers' own weed-control methods and to assess the payoffs of additional weed control over the existing system. This effort will help to develop an understanding of the crop, soil, climatic, and social situations in which improved weed management could have the greatest impact.

A minimal forage-crop program is being initiated to evaluate forage grass and legume mixtures as to their yield of palatable forage, soil-erosion control, longevity through hot and dry seasons under heavy grazing pressure, and rapidity of regrowth at the onset of the rainy season. These features are important for management of grassed waterways and tank bunds. The "Steps in Improved Technology" experiment will be continued with sorghum on Vertisols and pigeonpea/pearl millet intercrop on Alfisols.

Watershed-based Resource Utilization Research

The watersheds described in Table 64 represent ICRISAT's field laboratory for "systems research." Here the concept of a watershed-based farming system is examined on an operational or field scale, using animal draft power. This involves the monitoring of data on a Wide range of activities - which include inventories of natural resources, complete water-balance studies (measurements of rainfall, rainfall intensity, runoff, soil erosion, nutrient loss, consumptive use by plants, and deep percolation into shallow groundwater), investigations of rainfall-use efficiency, total annual production, human labor and bullock power utilization, and fertilizer, pesticide, and other material inputs used in the systems. The data are interpreted for each of the soil-, water-, and crop-management treatments on Alfisol and Vertisol watershed units.

Since water is the first limiting natural factor for crop production in the SAT, improving the management of the water and the soil for increased crop production becomes the primary aim of the Watershed-based Resource Utilization research. In rainfed agriculture, only the rain which falls in a given area is used, thus the watershed or catchment is the natural focus for studies of water management in relation to crop production, resource conservation, and utilization.

In the operational-scale research phase, economic evaluations are made in cooperation with the staff of the Economics program. All labor and draft-animal time spent in each watershed unit is recorded. At the end of each crop year, the input-output data from each of the watershed-management treatments being compared is assembled and reviewed. Measurements of relative profitability, rates of return on capital, labor, and animal power use, etc., are made and those treatments which appear consistently promising can be singled out for further study. Data from ICRISAT and other research institutions are also being employed in studies involving modelling and simulation of rainfall-runoff relationships and crop yield-moisture responses. The objective here is to assess the potential for water harvesting and supplementary irrigation under a

Table 64. Land-, water-, and crop-management treatments on watersheds at ICRISAT Center.

Watershed[a]		Planting method	Technology used[c]	Bund type[d]	Runoff Storage (m^3)[e]
No.	Area[b]				
Deep Vertisols					
BW1	3.41	Bed (0.6%)	Impr	Graded	-
BW2	3.96	Bed (0.6%)	Impr	Field	-
BW3A	5.21	Bed (0.4%)	Impr	Graded	4000
BW3B	2.15	Flat	Impr	Field	4000
BW4A	3.07	Flat	Impr	Field	-
BW4B	2.48	Flat	Impr	Graded	4000
BW4CN[f]	1.31	Flat	Impr	Field	-
BW4CS[f]	2.14	Flat	Trad	Field	-
BW5BN[f]	0.45	Bed (0.4%)	Impr	Graded	-
BW5BS[f]	0.67	Bed (0.4%)	Trad	Graded	-
BW6A	1.67	Flat	Trad	Field	-
BW6BN[f]	2.90	Flat	Impr	Contour	-
BW6BS[f]	1.79	Flat	Trad	Contour	-
BW7A	3.74	Bed (0.6%)	Impr	Graded	2000

continued

Table 64 *continued*

Watershed[8]		Planting method	Technology used[c]	Bund type[d]	Runoff Storage (m3)[e]
No.	Area[b]				
Medium Deep and Shallow Vertisols					
BW6C	2.66	Flat	Impr	Contour	-
BW6D	1.80	Flat	Impr	Contour	6500
BW7B	2.70	Bed (0.6%)	Impr	Graded	2250
BW7C	2.54	Bed (0.6%)	Impr	Graded	1750
BW7D	4.09	Bed (0.1%)	Impr	Graded	4100
BW7E[g]	0,89	Bed (0.6%)	Impr	Graded	-
BW7F[g]	0.73	Bed (1.0%)	Impr	Graded	500
BW8A	2.37	Flat	Trad	Field	-
Alfisols					
RWIC	0.86	Flat	Impr	Graded	2900
RW1D	1.15	Bed. (0.6%)	Impr	Graded	2900
RW1E	1.58	Flat	Impr	Graded	2900
RW2B	2.87	Bed (0.6%)	Impr	Graded	12000
Grassed Watersheds					
BW12	2.25	-	Ungrazed	-	-
RW3A	2.87	-	Ungrazed	-	-
RW2A	28.90[a]	- Grazed		-	-

[a]The two cropping systems applied on deep Vertisol watersheds BW1, BW2, BW3 A, BW3 B, BW4 B, BW7 A, and on medium deep Vertisol watersheds BW6 C/D, BW7 B, BW7 C, BW7 D, BW7 E, and BW7 F consisted of a maize/pigeonpea intercrop and maize followed by a sequential chickpea crop.
Deep Vertisol watersheds BW4A and BW6A were sown to a sorghum/pigeonpea intercrop and sole sorghum.
Deep Vertisol watersheds BW4C, BW5 B, and BW6 B were fallowed in the rainy season; sorghum and chickpea were grown in the postrainy season. On medium deep Vertisol watershed BW8 A, a sorghum/pigeonpea intercrop and a sole sorghum crop were grown.
On Alfisol watersheds, sorghum, groundnut and a Setaria/pigeonpea intercrop were grown in the rainy season and a ratoon sorghum crop was grown in the postrainy season. (Varieties and yields are given in Tables 71, 72, and 73.)

[b]All areas in hectares; large portions of BWS B, BW8 B and RW2 are not included, these areas are used for field-scale replicated experiments.

[c]Improved technology Indicates the following: Improved cultivars. Improved implements with animal power. Initial land preparation (plowing) on Vertisols immediately after harvest of the last crop to»kill weeds and stubble; land preparation is completed during the extended dry season. On Alfisols, initial plowing is executed whenever an early shower occurs. Grassed waterways are established. Plant protection is executed with minimum use of pesticides. Fertilization: 75 kg/ha of 18-46-0 at planting and 67 kg N/ha side-dressed.
Traditional technology simulates local practices: Local varieties. Traditional implements with animal power. Tillage is started after rains soften the soil. Farmers' field bunds remain the field boundaries. Plant protection with minimum use of pesticides. Fertilization: Farmyard manure at 50 cartloads/ha every second year.

[d]Graded bunds in bed plantings are low terrace-cum-channels which serve as drains for the bed-and-furrow system and as turn space. Graded bunds in flat plantings are broad bunds with a channel of 0.4 % grade. Field bunds are the original villagers' field boundary bunds. Contour bunds are of standard size and design according to locally adopted specifications.

[e]Several watersheds are sometimes served by the same runoff storage facility (e.g. BW3 A, BW3 B, and BW4 B); those watersheds, where supplemental irrigation is available, are frequently divided into a North and South (or East and West) section, water being applied to only half of the watershed.

The rainy season-fallow watersheds (4 C, 5 B and 6 B) are in the postrainy season divided into subunits where improved and local technology is applied.

(The watershed units BW7 E and F have been eliminated from comparisons because of the presence of eroded soils, salinity, and a disproportionate area under field bunds (see Table 70).

wide range of agroclimatic and economic environments.

By investigating all facets of resource inventory, development, management, and utilization and all factors involved in crop production in a systems approach, ICRISAT scientists expect to develop alternative viable systems for farmers in the SAT. Although the research is focused on the small farmers of limited means who comprise the majority of the farm population of the SAT, the large farmers who occupy much of the land and employ most of the labor are also expected to benefit.

Watershed Operations and Development

Research Watersheds on Vertisols and Alfisols

The locations and layout of present and proposed research watersheds were presented in ICRISAT's Annual Report for 1975-1976. Some important characteristics for each watershed unit studied during the 1976—1977 seasons have been summarized in Table 64. On the basis of previous results, a broad-bed system of 150 cm width was applied to several watersheds (Fig 80).

On the deep Vertisols, crops were again planted in dry soil during the first half of June. Experience over the past 4 years shows that this practice appears quite suitable for establishing crops early, thereby gaining in effective length of growing season and in attaining greater rainfall-use efficiency. H owever, the success of this technique depends upon: (i) the feasibility of planting relatively deep (>6 cm) to protect the seed from germination after early, small showers and also upon seedling tolerance to potential drought stress (e.g. sorghum, pigeonpea, and maize), (ii) sufficient reliability that after the selected sowing date, rains-once they begin-will continue [the probability of a rainy week (> 20 mm) followed by another rainy week must exceed 45%], and (iii) absence or control of rodents or other factors which might damage the seed in dry soil.

Figure 80. One row of pigeonpea and two rows of a cereal crop on a 150-cm bed on a Vertisol at 1CR1SA T Center.

Watershed Development and Feasibility Studies

Lined, elevated inlets for runoff storage units (tanks) were used previously to create above-ground storage and thereby increase storage-to-excavation ratios in BW7. Satisfactory experience with unlined inlet channels justified the removal of the cement and stone slab lining from the BW7 B tank which decreased costs from Rs 2.22/m^3 of storage to about Rs 1.75/m^3. Previous tank construction in BW7 was executed using exclusively human labor and draft animals. A new tank was constructed below BW8 using 40 hr of bulldozer time to build the elevated inlet channel and the bund up to the elevation where the bund width was adequate for efficient dozer use; labor was then used to finish further bund construction and shaping. This circular tank (capacity 4800 m^3, storage/excavation ratio = 2.6) was completed at a cost of Rs 1.10/m^3 of storage (Fig 81); these results compare favorably with earlier tank development costs in BW7 which ranged from Rs 2.00 to 2.50/m^3 of storage.

Figure 81. The BW8 tank partially filled following intense August storms.

Water-balance Studies

Runoff

In watersheds on deep Vertisols, which were cropped in the rainy season and cultivated to graded beds, 7 to 10 percent of the seasonal rainfall ran off; while under flat-planted conditions runoff varied from 10 to 17 percent (Table 65). Runoff from the BW3 B watershed exceeded that observed from BW1 and BW3 A. These observations again confirm the hypothesis that a bed-and-furrow system can be effectively used to uniformly conserve moisture on the land. This is also evident from Table 66; in 1973 and 1974, when the BW3 B watershed was cultivated to a 0.8- and 0.4-percent graded ridge-and-furrow system, respectively, runoff from this area was very similar to that on BW1 which has always been maintained in a 0.6-percent graded-ridge treatment. In 1975 and 1976 when BW3 B was changed to a 1-percent graded-ridge system and flat field-bunded conditions, respectively, runoff was (in relation to BW1) considerably increased.

Runoff under cropped contour-bunded conditions (BW6 C/D) was of a magnitude similar to the bed-and-furrow watersheds; however, in this situation additional infiltration occurred on only a small portion of the land and drainage problems frequently existed due to stagnant water above the bund. (See Land and Water Management subprogram.) Runoff on cropped, bedded, medium deep Vertisols (BW7 B,C,D, and F) amounted to about 10 percent with somewhat higher values on steeper (1.0%) slopes.

The largest quantities of runoff were observed under rainy season fallow, field-bunded conditions; on BW4 C about one-third of the seasonal rainfall (and 74% of the 21 Jul and 18, 19 Aug precipitation) ran off. A comparison of the "fallowed" watersheds BW4 C, BW5 BS and BW6 B indicates that broad beds in a rainy season fallow situation affect total runoff to a similar degree as contour bunds. However, the disadvantage of inadequate drainage on part of the land (Fig 82), associated with contour bunds, does not exist under ridged conditions; planting can be executed within a few days after rain. Although this management system is not suitable for Vertisols at ICR1SAT Center, this finding may be relevant in those areas where the early rainy season showers are less dependable and thus "dry planting" is more risky. Peak runoff rates observed this year (and also earlier) indicate that under cropped bedded conditions and under rainy season fallow, values of 0.05 to 0.1 and 0.1 to 0.15 m^3/sec per ha, respectively, are obtained.

Except under contour-bunded situations, runoff on the Alfisols amounted to about 20 percent of the seasonal rainfall (Table 67). On shallow soils runoff was considerably increased by beds and furrows (RW1 D); in case runoff is collected for later re-use, this may be desirable on light soils as long as erosion is not excessive. During high-intensity long-duration storms, almost 50 percent of the rainfall was lost under flat as well as bedded planting. Peak discharge rates on these soils generally range between 0.15 and 0.20 m^3/sec per ha.

Erosion

Soil losses measured at watershed outlets are presented in Table 68. Although the observed

Table 65. Rainfall, runoff, and peak-discharge rates on Vertisol watersheds at ICRISAT Center, 1976.

Watershed	Treatment[a]	Totals (rainy season) Rainfall	Runoff	Runoff	Totals 21 Jul and 18, 19 Aug[b] Rainfall	Runoff	Runoff	Peak[c]
		(mm)	(mm)	(% of RF)	(mm)	(mm)	(% of RF)	(m^3/sec per ha)
BW1	Bed, 0.6% slope	687	73	10.6	246	63	25.7	0.09
BW2	Bed, 0.6% slope	681	53	7.7	237	50	21.1	0.06
BW3 A	Bed, 0.4% slope	684	51	7.5	236	50	21.2	0.06
BW3 B	Flat, bunds	699	105	15.1	247	82	33.3	0.07
BW4 A	Flat, bunds	702	72	10.3	247	65	26.2	0.06
BW4 B	Flat, Gr. bunds	687	98	14.2	243	89	36.6	0.09
BW4 C	Fallow, bunds	710	238	33.5	245	182	74.2	0.16
BW5 BS	Fallow, bed, 0.4% slope	695	115	16.6	248	81	32.7	0.13
BW6 A	Flat, bunds	695	124	17.8	248	99	39.8	0.12
BW6 B	Fallow, C. bunds[d]	695	96	13.9	248	80	32.1	0.05
BW6 C/D	Flat, C. bunds	679	126	18.5	238	84	35.5	—
BW8 A	Flat, bunds	690	43	6.3	252	40	15.7	0.07
BW12	Nat. Veg.	696	71	10.2	203	46	22.7	0.04

[a] All watersheds except those indicated as fallow were cropped during the rainy season.
[b] The three highest-intensity storms during 1976 occurred on 21 July and 18 and 19 August.
[c] The maximum discharge observed during any storm (in all cases on 19 Aug) at the watershed outlet.
[d] The measured runoff from BW6 B and BW6 C and D is not corrected for quantities stored above contour bunds during successive storms; actual runoff is therefore greater in this situation.
NOTE: Due to malfunctioning of the water-level recorder and measuring structure, reliable runoff data were not obtained for BW5 N. Runoff quantities, estimated from tank records on BW7 A, B, C, D, and F amounted to 80, 87, 91, 97, and 96 mm respectively.

Table 66. Rainfall and runoff on BW1 and BW3B at ICRISAT Center, 1973 through 1976.

	BW1			BW3 B		
Year	Treatment	Rainfall	Runoff	Treatment	Rainfall	Runoff
		(mm)	(mm)		(mm)	(mm)
1973	Ridged 0.6%	700	45	Ridged 0.8 %	660	44
1974	Ridged 0.6%	810	116	Ridged 0.4%	810	105
1975	Ridged 0.6%	1040	161	Ridged 1.0%	1050	193
1976	Beds 0.6 %	690	73	Flat	700	105

Figure 82. Ponded water above a contour bund on rainy season fallowed land.

erosion from cropped catchments on Alfisols generally exceeded that which occurred in similar deep Vertisol situations, all quantities are well within acceptable limits.[9] The presence of graded beds and furrows under rainy season fallow conditions reduced erosion considerably compared to a flat, field-bunded situation (Table 68, BW5 B vs. 4 C); the observed difference would be even greater if erosion within watersheds were considered (Fig 83). The highest intensity long-duration storm (on 19 Aug) caused 80 percent of the seasonal soil loss under rainy season fallow in a flat field-bunded watershed (BW4 C). Soil erosion apparently increases much more with greater rainfall intensities under rainy season fallow than under cropped beds and furrows (Fig 84).

Figure 83. Channel deposition in an uncropped Vertisol following a heavy late-season rain at ICRISAT Center.

[9]The runoff collection tank on BW5 A (about 6.5 ha) was cleaned from sediment deposited in 1974, 1975, and 1976; the total quantity of eroded material removed was 18 metric tons, an average of less than 1 ton per hectare annually.

An experiment comparing broad beds and furrows with flat cultivation at 0.4- and 1.0-percent slopes was conducted on an Alfisol by K. A. Shams, a graduate student from Sudan.[10] The first runoff-producing storm occurred 18 days after planting a sorghum/pigeonpea intercrop when the crop was small (Leaf Area Index of 0.3) and thus did not provide much plant cover. Even though treatments did not influence the amount of runoff, the amount of erosion under flat cultivation was 2.7 times that of the bed-and-furrow system (Table 69). There was no significant difference between slopes, but the erosion tended to be higher at the 1.0-percent slope. The pattern of subsequent storms was similar; however, the amount of erosion per rain was greatly reduced and the magnitude of differences much less due to the overriding effect of the increased plant cover later in the season.

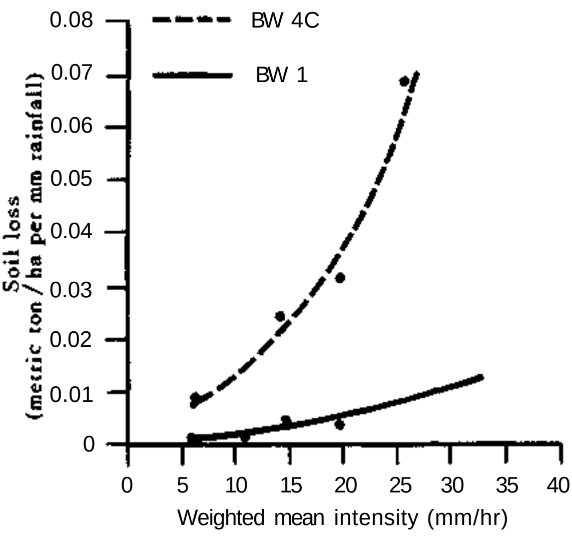

Figure 84. Effect of rainfall intensity on soil loss in a fallowed (BW4 C) and a cropped (BW1) watershed on a deep Vertisol.

[10]Shams, K. A., 1977. "The effect of bed vs. flat cultivation at two slopes upon runoff, erosion, crop growth, and yield." Thesis submitted to Andhra Pradesh Agricultural University in partial fulfillment of the requirements for the degree of Master of Science in Agriculture.

Table 67. Rainfall, runoff, and peak-discharge rates on Alfisol watersheds at ICRISAT Center, 1976.

Watershed	Treatment[a]	Totals (rainy season)			Totals 21 Jul and 18, 19 Aug[b]			
		Rainfall	Runoff	Runoff	Rainfall	Runoff	Runoff	Peak
		(mm)	(mm)	(% of RF)	(mm)	(mm)	(% of RF)	(m^3/sec per ha)
RW1 C	Flat, Gr. bund	661	140	21.1	228	108	47.5	0.16
RW1 D	R/F, 0.6%	685	190	27.8	231	137	59.2	0.22
RW1 E	Flat, C. bunds	703	85	12.1	232	79	33.9	0.06
RW2 B	R/F, 0.6%	649	141	21.7	233	120	51.3	0.19
RW2 A	Grazed	648	85	13.2	231	71	30.8	0.09
RW3 A	Nat. Veg.	672	12	1.8	209	10	4.9	0.02

[a]All watersheds except 2 A and 3 A were cropped during the rainy season; 3 A is a watershed where the climax vegetation is allowed to restablish itself, this area is not grazed. Although uncontrolled grazing takes place on 2 A, the area is characterized by several depressions; some bunds have also been constructed.
[b]The three highest-intensity storms during 1976 occurred on 21 July and 18 and 19 August.

Table 68. Erosion on Vertisol and Alfisol watersheds at ICRISAT Center, 1976.

Watershed	Treatment	Soil loss
		(kg/ha)
BW1	R/F,0.67%	800
BW2	R/F,0.6%	300
BW3A	R/F, 0.4%	300
BW4A	Flat, bunds	700
BW4B	Flat, Gr. bunds	900
BW4C	Fallow, bunds	9200
BW5B	Fallow, R/F, 0.4%	3800
BW6A	Flat, bunds	2200
BW6C/D	Flat, C. bunds	200
BW8A	Flat, bunds	500
RW1C	Flat, Gr. bunds	2000
RW1D	R/F, 0.6%	1800
RW1E	Flat, C. bunds	400
RW2B	R/F, 0.6%	2000

Table 69. Soil erosion from first erosive storm (90 mm on 21 Jul 1976) on an Alfisol at ICRISAT Center.

Cultivation method	Percent slope		Mean
	0.4	1.0	
	(kg/ha)	(kg/ha)	(kg/ha)
Flat	852	1309	1081
Broad ridge	327	470	399
L.S.D. (0.05)			365

Groundwater

Most groundwater levels, measured at piezometers, indicate no substantial change between May 1976 and May 1977 (Fig 85). An exception is found where observations were taken near to newly constructed Lake ICRISAT (BW8). On deep Vertisols, the groundwater levels increased by about 250 cm during the rainy season; this is equivalent to approximately 160 mm of water.[11] Thus, about 25 percent of the seasonal rainfall percolated through the root profile. On shallow and medium deep Vertisols, the storage capacity of the root profile is filled more rapidly and therefore groundwater levels increase earlier than in the deep Vertisols (Fig 85); the total quantity percolated through the profile during the rainy season amounted to about 265 mm, or 40 percent of the precipitation. On the shallow Alfisol watersheds, the quantity of water lost to groundwater can, from lysimeter observations, be estimated at about 230 mm, or about 35 percent of the rainfall. Thus, even during a rainy season of moderate total precipitation, very large quantities of moisture may be lost from the root zone particularly if, as in 1976, the duration of the rainy season is short while the total seasonal quantities are near normal.

Crop Season Evapotranspiration

Detailed data on evapotranspiration of several crops during both seasons were collected by the Soil Physics subprogram making use of lysimeters, neutron moisture probes, and tensiometers installed on watershed units (see page 144). The precipitation from 1 to 21 June (about 35 mm) did not contribute to plant growth, although final presowing cultivation was facilitated. The evapotranspiration of a sole maize (cv Deccan Hybrid 101) crop of 100 days duration, grown on deep Vertisols, was estimated at 350 mm; rainfall was well distributed and crops were not subject to drought stress. Maize (cv SB-23) grown as an intercrop in pigeonpea was of 93 days duration, and the evapotranspiration of the intercrop combination was estimated at about 310 mm up to maize harvest time. No detailed data were collected on medium deep and shallow Vertisols; however, no serious wilting of crops was observed and therefore similar figures may be used. On the basis of lysimeter data from medium deep Alfisols, it can be estimated that

[11] The groundwater component is computed on the basis of an estimated S % available storage capacity of the deep subsoils.

the evapotranspiration for sorghum (CSH-6) was approximately 340 mm; although sorghum is of longer duration than maize, once dry weather had set in during September, wilting was observed in both sorghum and groundnut on RW1 and RW2.

Beginning after the first week of September, soil moisture levels started to decline and post-rainy season crops were sown under extremely dry conditions; emergence was poor and stands inadequate in nonirrigated areas. Newly planted sorghum on deep Vertisols can be estimated to have used about 200 mm of water (1.70 mm of profile moisture and 30 mm of rainfall). Where chickpea was sown on previously fallow deep soils, or where it was irrigated (with about 60 mm) after planting, the evapotranspiration during the postrainy season can be estimated at approximately 180 mm. Chickpea sown as a second crop without supplemental irrigation may not have used more than 75 mm on the deep Vertisols and even less on medium deep soils. The evapotranspiration of a ratoon sorghum crop on deep Vertisols amounted to less than 130 mm; on Alfisols, where the ratoon sorghum was irrigated twice, only about 125 mm was used. Pigeonpea grown on deep Vertisols used about 175 mm after the maize harvest.

The estimates of postrainy season evapotranspiration on Vertisols do not include contributions through upward water movement from soil layers below 180 cm depth. There is some

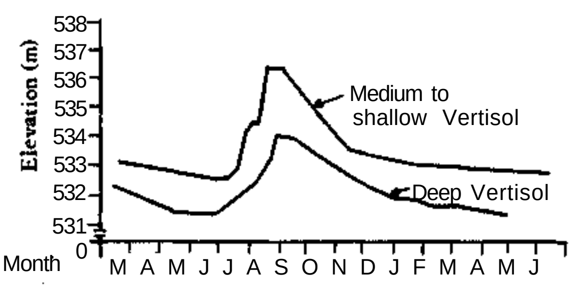

Figure 85. Comparison of seasonal changes in groundwater levels in a medium to shallow Vertisol and a deep Vertisol. Surface elevation of the medium to deep Vertisol is 533.02 meters; that of the deep Vertisol is 537.82 meters.

evidence that this quantity, particularly in a dry postrainy season like 1976, can be quite substantial. From moisture data collected in June 1976 and May 1977, it appears that total profile moisture up to 180 cm depth decreased by about 30 mm during this period.

In conclusion, total evapotranspiration of the intercropping systems of maize and pigeonpea can on deep Vertisols be estimated at about 485 mm (310 and 175). When sequential crops of maize and chickpea were grown without irrigation, the total evapotranspiration was 425 mm (350 and 75); when the chickpea was supplementally irrigated up, approximately 530 mm (350 and 180) was used. In situations where only a rainy season crop was grown on Vertisols, seasonal evapotranspiration probably did not exceed 400 mm even where somewhat longer-duration crops were used. Only approximately 200 mm was used if a single postrainy season crop was grown. On Alfisols, the total evapotranspiration of sorghum followed by an irrigated ratoon crop was approximately 465 mm (340 and 125). The evapotranspiration of a single rainy season crop on Alfisols was about 340 mm.

Runoff Collection and Use

Substantial quantities of runoff occurred only twice during the rainy season. In tanks with high seepage rates - such as most of those on BW7 - much of the water collected during the first runoff event in July had disappeared by the time high-intensity rains of sufficient duration occurred again in August. A sequential crop of chickpea was sown around 5 October on Vertisols planted to sole maize in the rainy season. Soil moisture had by this time receded to such depths that planting into the moist zone by animal-drawn equipment was successful in only part of the watershed areas, thus very uneven stands resulted. Because rainfall probabilities are high in September and early October [the probability of a wet week (20 mm) following a dry week generally exceeds 50 %], supplemental irrigation was delayed until mid-October.

When it was decided to apply water to chickpea on Vertisols for germination and stand establishment and to sorghum on Alfisols for ratooning, water remained in only the BW3, BW5, BW6, BW7 A and D, RW1, and RW2 taiaks. For deep tanks, less than 10 percent of the collected water evaporated. From 10 to 90 percent of the stored water was lost due to seepage in different tanks; the greatest seepage losses occurred in medium deep Vertisols. The relative quantity of water actually used from tanks therefore varied considerably-on BW3 about 85 percent of the collected runoff was applied to the land. This is equivalent to approximately 40 mm on the contributing watershed. On the RW1 watershed, the quantity used for supplemental irrigation amounted to only 45 percent of that collected. However, because of greater runoff from these soils, this was equivalent to about 85 mm.

Yield response under supplemental irrigation compared to crops grown on residual moisture alone varied considerably, due to differences in stand establishment at the beginning of the dry season for both chickpea and ratooned sorghum. A 20-mm rain occurring 6 November caused most of the nonirrigated chickpea to germinate, which further complicated comparisons. For example, on BW3 A (broad-ridged) supplemental irrigation (80 mm) at planting increased yields on the average from 780 to 1 310 kg/ha; under flat-sown conditions the respective yields were 480 and 850 kg/ha on BW3 B and 310 and 560 kg/ha on BW4 B. General yield levels on the medium deep Vertisols were lower; supplemental irrigation at planting increased yields on BW7 B from 500 to 1000 kg/ha and on BW7 C from 320 to 1080 kg/ha. The effect of supplemental irrigation on ratoon sorghum on Alfisols was disappointing, yields on RW2 B increased from 540 to only 1060 kg/ha after two irrigations of 50 mm each, one at time of harvest of the first crop and a second during heading of the ratoon crop.

Water Balances and Effective Rainfall

In deep Vertisols the total evapotranspiration during the crop season for the intercrop situations was about 485 mm and for sequential cropping approximately 425 mm. This "effective rainfall"[12] constituted about 70 and 60 percent respectively of the total rainfall in the growing season. Of the remaining portion of the precipitation, around 10 percent was lost as runoff and 25 percent disappeared from the profile contributing to groundwater. In watershed units where runoff was collected and re-used for chickpea, the actual runoff loss decreased by about half; however, effective rainfall was increased to almost 70 percent because of greater profile-water use under supplemental irrigation. Minor discrepancies in the water balance may be explained by small changes in the profile-moisture status or by inaccuracy of the groundwater estimate. On double-cropped flat-planted watershed units, the effective rainfall may have been of similar magnitude. Runoff averaged around 15 percent, thus the groundwater recharge was slightly less at about 20 percent.

The application of improved technology on the medium deep Vertisols resulted (on somewhat steeper slopes under ridged conditions) in a runoff of about 10 percent; however, the portion of the precipitation contributing to groundwater was much larger (around 40 %) due to the limited moisture-holding capacity of these soils. Therefore, effective rainfall contributing to crop growth on these medium deep soils amounted to only about 50 percent of the rainfall. The relatively low effective rainfall on the medium deep Vertisols is an important factor explaining the low yields obtained from the postrainy season crops.

On the Alfisols, runoff amounted to 20 to 25 percent of the precipitation in ridged systems; the groundwater component can be estimated at 35 percent and the actual evapotranspiration of a rainy season crop at only about 45 percent.

The traditional practice of growing only one crop, either in the rainy season or in the postrainy season, resulted in a relatively low effective rainfall. On deep Vertisols where a rainy season crop was grown, the actual evapotranspiration

[12] "Effective rainfall" is defined as the percentage of the precipitation during the crop season (for a two-crop system, generally taken as 1 Jun to 1 Feb) actually used as evapotranspiration by a soil-crop complex.

was no more than 50 percent of the seasonal rainfall, about 20 percent ran off and 25 to 30 percent percolated down to groundwater. On medium deep soils there was less runoff and therefore a proportionately greater groundwater component. The rainy season-fallow system, as in previous years, resulted in the smallest effective rainfall (25-30 %), large quantities of runoff (35%), and a substantial groundwater contribution (much of the rainfall in this system is lost as evaporation from bare soil and transpiration from weeds during the rainy season).

From the discussion of water balances, it is evident that even in a relatively low rainfall year, very substantial quantities of water are not available for crop production due to runoff and deep percolation from the profile. Approximately the same rainfall occurring on deep and medium deep Vertisols and Alfisols resulted in greatly different moisture environments for plant growth, length of growing season, and total water use. In 1976, management methods resulting in decreased runoff had as their primary effect an increased groundwater component. At ICRISAT Center and in many similar situations across the SAT, groundwater is not easily accessible due to poor aquifer conditions. Thus, two areas of research need to be further emphasized - (i) exploration for a better use of the root profile storage capacity and (ii) testing of management methods which increase runoff into small watershed tanks (particularly in the later part of the rainy season) without causing significant erosion.

Crop Production and Economic Data

The main objective of resource development and management is to increase agricultural production on a sustained basis. To accomplish this goal, systems must be developed which can effectively utilize the current season's rainfall directly, as well as supplemental water from available surface-stored water and/or groundwater. This system must also minimize soil erosion and conserve resources for future generations. By researching alternative soils- and crop-management systems in field-scale operational units, it is possible to study means of increasing and stabilizing production as well as potentials for reducing peak labor and draft-power demands. Emphasis is being given to the development of "non-monetary" inputs such as timeliness of operations and improvement of soil- and crop-management practices in order to optimize the returns from improved seed, fertilization, plant protection, and improved animal-drawn equipment.

Yield Comparisons of Harvest of Random Samples vs. Entire Plots

In most watersheds, entire replicates (0.2 to 0.8 ha) were harvested and yields determined after randomly selected yield samples had been taken. In sole maize, the average yield computed from the sample-based system was 120 kg/ha less than that of the whole-plot-based system. In the case of intercropped maize, the average of the sample-based yields were 75 kg/ha less than the plot-based yields. Thus, it appears that the random-sample harvest procedure gives a sufficiently accurate measure of whole-plot yield.

In order to obtain information on the net production in each watershed unit, yields were adjusted according to the actually cropped area in each watershed. In other words, the area occupied by field bunds, contour bunds, and grassed waterways was subtracted in order to obtain the percentage of net cropped area in each watershed unit. As shown in Table 70, there is considerable variation in net cropped area; this is particularly true in BW2 where wide field-boundary bunds were retained and in the small units in the lower part of BW7.

Crop Production on Vertisols

In 1976, two cropping systems (a maize/pigeonpea intercrop and sole maize followed by a chickpea sequential crop) were adopted on most of the watershed units on the Vertisols. In other units, sorghum/pigeonpea intercropping and

Table 70. Total land area and percentage net cropped area in the Vertisol watershed units at ICRISAT Center.

Watershed	Total area	Net cropped area
	(ha)	(%)
BW1	3.41	95
BW2	3.96	87
BW3A	5.21	89
BW3B	2.15	92
BW4A	3.07	91
BW4B	2.48	87
BW4C	3.45	97
BW6A	1.67	86
BW6B	4.69	90
BW6C	2.66	79
BW6D	1.80	87
BW7A	3.74	84
BW7B	2.70	81
BW7C	2.54	81
BW7D	4.09	80
BW7E	0.89	78
BW7F	0.73	62
BW8A	2.37	93

sole sorghum plus ratoon-cropping systems were grown. These double-cropping systems were compared to traditional postrainy season single cropping under different soil- and water-management practices (Table 71). Each cropping system was duplicated in each watershed unit and the crop yields and rupee values given are means of the two replicates. Yield and economic data presented in Tables 71, 72, and 73 are from nonirrigated areas.

On deep Vertisols, yields of the broad bed- and furrow-system (BW1, 2, 3 A) were higher than those in the adjacent flat-planted watersheds (BW3 B, 4 B). The average gross returns of the three bedded watersheds for the intercrop and sequential crop systems were Rs 4920 and Rs 3680 per ha, respectively (Table 71A). These values were Rs 710 and Rs 810 per ha higher than the comparable flat-planted systems. BW7 A was excluded from the comparisons because of poor growth due to inadequate drainage in past years (see footnote b., Table 71 A). In the sorghum-based system[13] gross benefits were about the same as in the flat-planted maize-based systems (Table 71). As in past years, the most striking contrast in production was that of the improved double-cropping on beds versus traditional flat-planted single cropping in the postrainy season. The gross benefit of traditional postrainy season sorghum was only Rs 950, or 19 percent of the improved intercrop system (Table 71A, C). Another disadvantage of the postrainy season single-cropping system is that clean cultivation is practiced four or five times during the rainy season, which leaves the soil unprotected and subject to raindrop erosion during high-intensity storms (see page 182).

The yields and gross monetary values of the maize/pigeonpea intercrop on both the deep and medium deep Vertisols were consistently much greater than that of the maize-chickpea sequence (Tables 71,72). This large difference in the 1976-1977 season was due to (i) poor-quality Deccan Hybrid 101 seed used in the sequential system, (ii) poor germination of chickpea due to severe drought in late September and October, and (iii) unusually high prices of pigeonpea at harvest time. In 1975-1976, the maize plus sequential chickpea was a good combination with maize and chickpea yields being about 50 and 100 percent higher, respectively, than in 1976-1977.

On the medium deep Vertisols, average yields and gross benefits in the bed-and-furrow watersheds at the 0.6-percent slope (BW7 B, C) were consistently better than those obtained under flat planting. However, the magnitude of the differences is less than on the deep Vertisols. Yields and gross benefits in BW7 D (beds at a 1.0% slope) were lower than those obtained with beds at 0.6-percent slope or flat planting. Yield values and gross benefits on the medium deep Vertisols

[13] Although the sorghum-based systems compare relatively favorably in 1976, this system was unsuccessful in the 3 previous years because of moist conditions at harvest time.

Table 71. Grain yields and rupee values of several farming systems on deep Vertisok at ICRISAT Center, 1976-1977.

Watershed No.	Planting method	Tech. used	Slope	Intercropping[a] Maize	Pigeon-pea	Gross value	Sequential cropping[a] Maize	Chick-pea	Gross value
			(%)	(kg/ha)	(kg/ha)	(Rs/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
A. Double-crop systems									
BVV1	Bed	Impr	0.6	3360	720	4870	3 310	600	3840
BW2	Bed	Impr	0.6	2910	900	4960	3090	450	3410
BW3A	Bed	Impr	0.4	3 590	670	4930	2970	760	3800
Mean				3290	760	4920	3120	600	3680
BW3B	Flat	Impr		3030	680	4470	2350	440	2750
BVV4B	Flat	Impr		2790	560	3940	2930	280	3000
Mean				2910	620	4210	2640	360	2870
BW7A[b]	Bed	Impr	0.6	2460	590	3730	2270	660	3030
B. Sorghum/pigeonpea intercropping and sole sorghum + ratoon crop[a]									
				Sorghum	Pigeon-pea	Gross value	Sorghum	Ratoon	Gross value
				(kg/ha)	(kg/ha)	(Rs/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
BVV4A	Flat	Impr		2580	670	4130	2720	700	3080
BW6A	Flat	Trad		540	390	1920	410	-	660
C. Single-crop systems (postrainy season only)[a]									
				Sorghum	Chickpea	Gross value			
				(kg/ha)	(kg/ha)	(Rs/ha)			
BW4CN	Flat	Impr		500	490	1230			
BW6BN	Flat	Impr		1480	-	1330			
Mean				990		1280			
BW4CS	Flat	Trad		600	-	660			
BW6BS	Flat	Trad		1130	-	1240			
Mean				870		950			

a. Varieties used: Improved -maize intercrop, SB-23; pigeonpea, ICP-1; sole maize, Deccan Hybrid 101; chickpea, local; sorghum CSH-6; Traditional -local.

b. The maize yields in BW7 A were only 74 percent of the average of the other deep Vertisol watersheds (BW1,2,3 A). Gross returns for the two cropping systems on BW7 A were about Rs 1190 and Rs 650/ha less than the average of BW1,2, and 3 A. This is due to the presence of some areas of medium deep soils and a poor growth area in the center caused by years of inadequate drainage. However, crop growth has substantially improved since 197S and it is expected that BW7 A will behave similarly within a few years. Nearby areas in STI showed poor growth in 1976 due to boron toxicity. This and other causes are being investigated.

Table 72. Grain yields and rupee values of several farming systems on medium deep Vertisols at ICRISAT Center, 1976-1977.

Ws No.	Planting method	Tech. used	Slope	Intercropping[a] Maize	Pigeon-pea	Gross value	Sequential cropping[a] Maize	Chick-pea	Gross value
			(%)	(kg/ha)	(kg/ha)	(Rs/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
A. Double-crop systems									
BW7D	Bed	Impr	1.0	2170	390	2940	2210	130	2270
BW7B	Bed	Impr	0.6	2060	620	3470	2460	410	3250
BW7C	Bed	Impr	0.6	2740	730	4350	2150	500	3220
Mean				2400	675	3910	2305	455	3235
BVV6C	Flat	Impr	Contour	2470	410	3260	1850	390	2660
BW6D	Flat	Impr	Contour	2040	690	3640	1760	310	2 370
Mean				2255	550	3450	1810	350	2520

B. Sorghum/pigeonpea intercropping and sole sorghum[a]

			Sorghum	Pigeon-pea	Gross value
			(kg/ha)	(kg/ha)	(Rs/ha)
BW8A	Flat	Trad	640	440	2210
BW8A	Flat	Trad	630	-	1010

[a]Varieties used: Improved - Maize intercrop, SB-23; Pigeonpea, ICP-1; Sole maize, Deccan Hybrid; Chickpea, local; Sorghum, CSH-6. Traditional -local.

were substantially less than on the deep Vertisols. This is believed to be due to greater moisture stress during the severe September drought and inadequate moisture for the postrainy season crops. Yields and benefits from bedded cultivation on both deep and medium deep Vertisols are likely to improve since the beds are left in place and soil structure in the broad beds is expected to improve due to reduced soil compaction.

The sorghum yield from rainy season cropping on BW8 A (traditional technology) was 630 kg ha (Table 72 B). It is interesting to note that sorghum and the addition of the pigeonpea intercrop more than doubled the gross monetary value. This was true even in a season when the rainy season rains stopped one month earlier than normal, which caused some moisture stress for the late-maturing pigeonpea.

Crop Production on Alfisols

Grain yields and monetary values for the three cropping systems used on the Alfisols (RW1 and 2) are given in Table 73. RW1 E, which was contour bunded and flat planted along the contour, consistently produced the lowest yield of the three cropping systems. The reduced yields appeared to be due to erosion and sedimentation between the bunds, which caused reduced plant stands and growth. The average gross value for the three cropping systems in the broad bed-and-furrow system treatment (RW1 D) was Rs 3 400, which is 39 percent greater than that of RW1 E (contour bunded) and 9 percent greater than RWI C which was flat planted along graded bunds at 0.6-percent slope.

The pigeonpea yield on the Alfisols was generally greater than that on the Vertisols in spite of the low September/October rainfall and the relatively lower moisture-holding capacity of the Alfisols compared to Vertisols. A possible reason for this is that the Setaria intercrop on the Alfisols matured earlier and therefore competition was removed at an earlier date than with maize (cv SB-23) and sorghum grown on the Vertisols.

Rainfall-use Efficiency

In a year of less-than-average rainfall, it becomes critically important to utilize all available water with utmost efficiency to maintain optimum levels and stability of crop production. Developing a system for 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. Thus, effective rainfall as well as "water-use efficiency" need to be optimized in order to arrive at a high and profitable "rainfall-use efficiency" (RUE).[14] The RUE's were calculated on the basis of crop production under alternative treatments in research watersheds (Tables 71, 72, 73). The estimated RUE values obtained from several farming systems on selected watershed units are listed in Table 74.

Gross RUE's varied from Rs 69/cm for a maize/pigeonpea intercrop in BW2 to only Rs 9/cm for sorghum grown with local technology after rainy season fallow on BW4 C. On deep

[14] "Water-use efficiency" is defined as the agricultural production (in yield or value) in relation to the actual crop-related evapotranspiration (in cm). "Rainfall-use efficiency" is the product of effective rainfall- and water-use efficiency.

Table 73. Grain yields and rupee values of alternative farming systems with improved technology on Alfisol watersheds at ICRISAT Center, 1976–1977.

Watershed No.	Planting method	Slope	Intercropping[a]			Sorghum[a]			Sequential cropping[a]		
			Setaria	Pigeonpea	Gross value	Main crop	Ratoon crop	Gross value	Groundnut	Safflower	Gross Value
		(%)	(kg/ha)	(kg/ha)	(Rs/ha)	(kg/ha)	(kg/ha)	(Rs/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
RW1 C	Flat	0.6	1 160	730	2 610	3 170	80	2 830	1 270	190	3 900
RW1 D	Bed	0.6	1 350	970	3 360	2 570	150	2 370	1 480	180	4 480
RW1 E	Flat	Contour	790	570	1 970	2 840	80	2 540	890	190	2 810
RW2 B	Bed	0.6	730	830	2 640	3 080	550	3 160	1 000	230	3 180

[a] Setaria, H-1; Pigeonpea, ICP-1; Sorghum, CSH-6; Groundnut, TMV-2; Safflower, S-11.

Table 74. Rainfall-use efficiencies obtained in alternative fanning systems on Vertisols and Alfisols at ICRISAT Center, 1976-1977.

Watershed No.	Cropping Systems and water use[a,b]	Value of produce	Gross RUE[c]
		(Rs/ha)	(Rs/cm)
Deep Vertisols:			
BW2	Maize/Pigeonpea	4960	69
	Maize/Chickpea	3410	47
BW3 A	Maize/Pigeonpea	4930	68
	Maize/Chickpea NS	3800	53
	Maize/Chickpea S	4511	63
BW4 A	Sorghum/Pigeonpea	4130	57
	Sorghum/Ratoon	3080	43
BW4C	Sorghum Local	660	9
	Sorghum Improved	1330	18
BW6B	Sorghum Local	1240	17
	Sorghum Improved	1330	18
Medium Deep Vertisols:			
BW7B	Maize/Pigeonpea	3470	48
	Maize/Chickpea NS	3250	45
	Maize/Chickpea S	3850	53
BW8 A	Sorghum/Pigeonpea	2210	30
	Sorghum	1010	14
Alfisols:			
RW2 B	Setaria/Pigeonpea	2640	40
	Sorghum and Ratoon NS	3160	49
	Sorghum and Ratoon S	3520	54
	Groundnut/Safflower	3180	49

[a] Total rainfall during the growing season (Jun to Feb) was 720 and 650 mm on BW1-8 and RW2, respectively.

[b] The symbol NS when added to a cropping system indicates that crops were grown rainfed and on residual soil moisture; the symbol S stands for the application of supplemental water.

[c] Gross RUE is the rainfall-use efficiency calculated on the basis of the total vaiue of the products grown in a cropping system.

Vertisols, the RUE values obtained on watersheds in broad beds were two to three times those obtained with traditional rainy season fallow with local and improved varieties. RUE's on medium deep Vertisols and Alfisols were substantially lower than those obtained in deep Vertisols. On both deep and medium deep Vertisols (at the 0.6 % slope) the RUE's obtained for intercrops and for the combined sequential crops were higher on broad beds than on flat-planted soils. There are clear indications that in years of early rainy season termination, the use of supplemental water to irrigate a second crop at planting time may be critical to substantially increase RUE on at least part of the land and to make it feasible to grow a sequential crop. On Alfisols, the RUE's on watersheds in broad beds generally exceeded those on flat-planted areas.

The range of RUE values clearly shows the potentials of improved resource use in a year of relatively low rainfall in the late rainy season. It is of course realized that RUE values derived from gross returns, although reflecting the actual quantity of production, only partially reflect the differences between alternative systems of farming because of differentials between the costs incurred in different systems. However, some tentative calculations show that when input costs are taken into account, the differences in RUE values between improved and traditional systems become even greater.

Implications and Future Plans

Experience in watershed-based research over the past few years and agroclimatic analyses show that in many years sufficient moisture is available on deep Vertisols for intercropping or sequential cropping consisting of a short-duration rainy season crop followed by a dry season crop; the early termination of the rains the past year has been an exception. However, harvesting, drying, and threshing of crops during the latter part of the rainy season and the susceptibility of most present sorghum and millet genotypes to grain mold and weathering pose a serious problem (as a temporary solution, maize is grown on many

Vertisol watersheds). Thus, to make intercropping and sequential cropping viable with species now grown widely in the SAT three options must be simultaneously investigated: (i) generation of short-duration genotypes which better withstand humid weather conditions at maturity and which either do not ratoon (to facilitate planting a sequential crop with minimum tillage) or will produce a viable ratoon crop; (ii) the development of harvesting, drying, and threshing techniques suitable for the rainy season, and/or (iii) the generation of determinate and high-yielding genotypes of 130 to 150 days duration and concurrently the development of supplemental irrigation availability for establishment of a sequential crop (or ratoon crop).

A large portion of the season's rainfall percolates through the root profile after the capacity of the soil to store moisture is exceeded; this process often begins before half of the rainy season is over and is of the greatest magnitude on medium deep Vertisols and Alfisols. Even on deep Vertisols, however, frequently as much as 20 percent of the rainfall contributes to groundwater. In many areas in the SAT this component cannot be easily recovered because of unsuitable aquifer conditions. Thus, it becomes important to investigate techniques which permit a more efficient use of available profile storage through greater extraction and/or which permit a larger portion of the rainfall to be collected in reservoirs during the later part of the rainy season for subsequent utilization.

During the past 4 years, it has been observed that on Alfisols substantial quantities of water escape early in the season when the profile is not yet fully charged, partly due to surface sealing. Means to increase infiltration of larger quantities of rainfall into the soil during the preplanting and establishment period must be sought.

When the Vertisol profile is fully charged at the beginning of the postrainy season, the opportunity for substantial returns from supplemental water is reduced. Saving the available water until the summer season usually means large evaporation and seepage losses. Therefore, longer-duration rainy season crops of high yield potential must be explored on deep Vertisols so that collected runoff can be used for profile recharge and second crop establishment. Ratooning of pigeonpea or postrainy sorghum are other possibilities which are being explored for effective use of stored water.

High seepage losses, particularly on medium deep Vertisols with gravelly subsoils, seriously limit the potential for supplemental irrigation from collected runoff. Although in some situations eroded sediment reduces losses while in others compacted salt/soil mixtures are effective, additional research on cheap but highly impermeable sealing materials is urgently needed.

Precision planting of seed at the exact final spacing required presents problems in many situations common in the SAT. The nonavailability in some areas of seed graded according to size, along with problems with germination, frequently results in plant populations of less than optimum. Gap filling, even if done early, does not result in satisfactory growth of late-planted material. It will therefore, often be necessary to overseed crops and later thin to the required plant density. Thus, there is a need for adjustable continuous-flow planters operating independently of seed size. There is also an urgent need to develop planting equipment which can be satisfactorily used over a wide range of soil moisture conditions.

Resource utilization research on natural watershed units of an operational size will be continued and intensified during the next few years. Five additional catchment units are being developed on Alfisols; efforts to develop approaches which substantially increase rainfall-use efficiency on these soils as well as on the medium deep Vertisols have so far had only limited success. Increased attention will be given to a better understanding of the movement of water in the soil profile-plant-atmosphere system operating under alternative resource-management and cropping systems. Ratooning of pigeonpea with or without the use of supplemental water, which appears promising (see "Steps in Improved Technology", page 171) will be applied on an operational scale. The use and conservation of collected runoff water, particularly where seepage rates are high, will be further investigated, Management systems resulting in greater runoff without significant erosion will be explored on soils with limited profile storage capacity. Research will be oriented towards operational problems related to harvesting, drying, and threshing of rainy season crops.

Research on alternative resource-management and cropping systems on an operational scale to increase and stabilize production in rainfed agriculture has been initiated at two Regional Centers by the All-India Coordinated Research Project for Dryland Agriculture. Possibilities for such cooperative research are being considered at other Centers. Data on improved resource management collected at several locations characterized by different agroclimatic conditions will provide a better base for extrapolation of research results and for early implementation of improved farming systems. Possibilities are being explored to test improved farming systems under real-world conditions in pilot projects to determine their social implications.

Cooperative Research

ICRISAT is one of the research centers where new concepts, approaches, and methodologies to arrive at improved farming systems will be generated. However, before application in the diverse regions of the SAT, these principles have to be integrated into viable packages or systems and adapted info 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. Also, 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 alternatives 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, etc.), dictates the need for associated research efforts at such locations. Preliminary investigations are under way to identify bench-mark locations in Africa.

During the past year, discussions with Indian research programs[15] have resulted in two cooperative research proposals which have been initiated at several locations across the Indian SAT.

Hydrologic studies to improve land and water utilization in small agricultural watersheds

The objective of this project is to derive region-specific design criteria for improved resource management which will more effectively conserve and utilize the rainfall and the soil and which, when integrated with new crop production systems, increase productivity and assure dependable harvests. The project has been started at Bangalore and Hyderabad.

Research on resource development, conservation, and utilization in rainfed areas

The objectives of this project are to develop a research program for testing the bed-and-furrow system of cultivation and its modifications under several agroclimatic conditions and also to quantify the production effects of presently accepted soil and water conservation practices. The proposed research locations are Akola, Bangalore, Bellary, Hyderabad, ICRISAT Center, Indore, Ranchi, and Sholapur.

[15]The All-India Coordinated Research Project for Dryland Agriculture and the Central Soil and Water Conservation Research and Training Institute.

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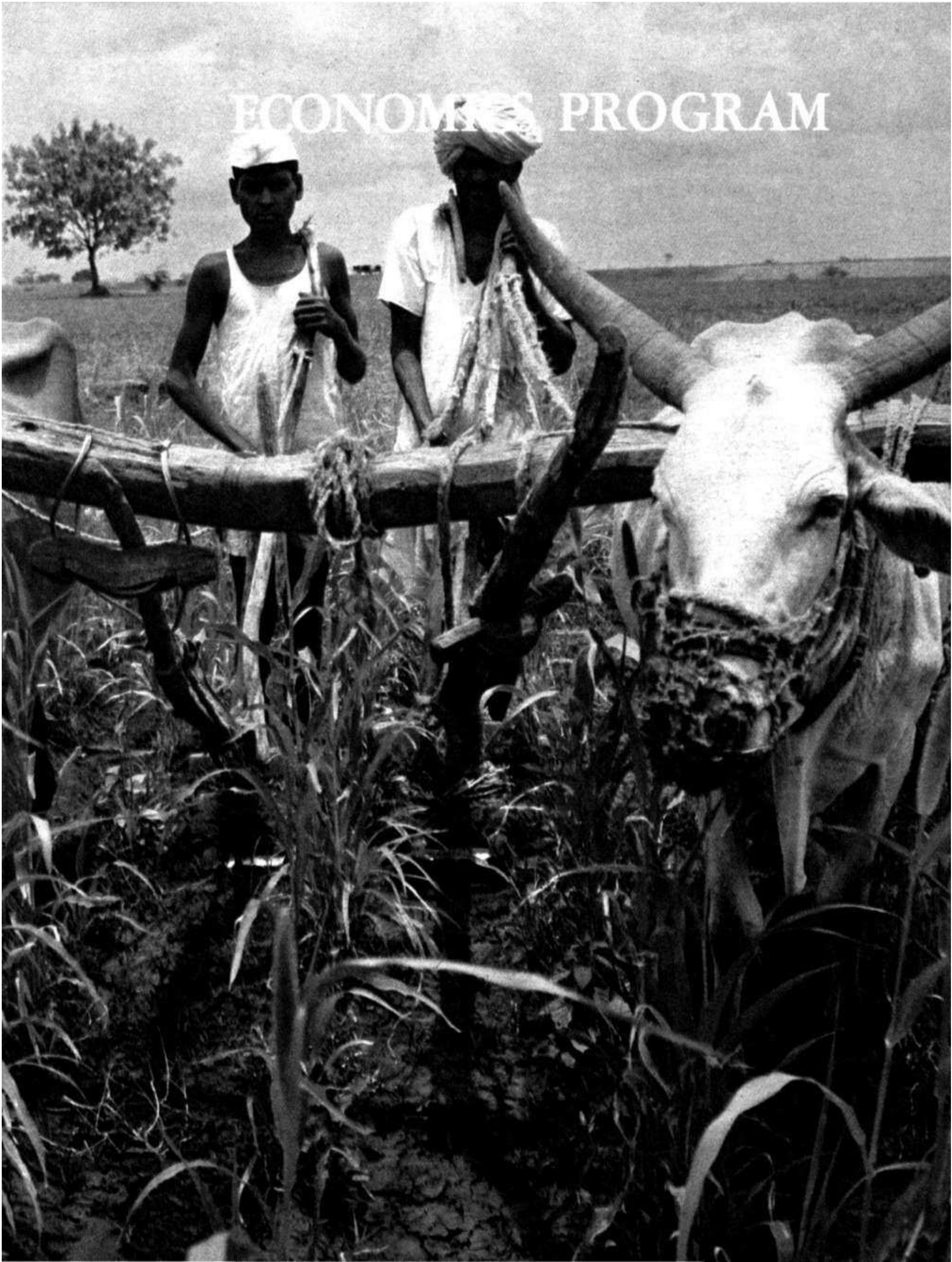
ECONOMICS PROGRAM



Economics Program

The Economics Program was able to essentially complete eight major research studies during the 1976-1977 year at ICRISAT. All were aimed at helping to identify the major socioeconomic and other constraints to agricultural development in the semi-arid tropics and to evaluate alternative technological and/or institutional measures required to alleviate these constraints. The main findings from the studies are discussed under the two subprogram headings of Production Economics and Marketing Economics.

Production Economics

Resource Base and Cropping Patterns

Results from the Indian village-level studies - which have been under way in six villages in three agroclimatic zones since May 1975- indicate large regional differences in cropping patterns. In the Sholapur District of Maharashtra, which generally has deep Vertisols, farmers plant nearly 60 percent of their crops in the postrainy season following a rainy season fallow (Fig 87). In the medium deep Vertisol area of Akola District, also in Maharashtra, almost all crops are sown in the rainy season. In the Alfisol villages of Mahbubnagar District, Andhra Pradesh, around 85 percent of the cropped area is sown in the rainy season. In Shirapur village of Sholapur District, which has very deep Vertisols, small farmers were found to keep a much higher proportion (78 %) of their lands fallowed during the rainy season compared to large fanners (55 %). If this is representative of the estimated 18 million hectares of land not cropped during the rainy season in SAT India, then technologies which enable crops to be grown in the rainy *as well as* the post-rainy season may contribute a proportionately larger impact on the small farmers, as well as substantially increasing food production.

Except in villages with little irrigation or without the very deep Vertisols which store moisture well for relatively assured postrainy season cropping, small farmers sow a higher proportion of their land to intercrop mixtures than do large farmers (Fig 88). The latter have a higher proportion of sole crops, but interestingly enough they grow many more different species of crops than do the smaller farmers. One might be tempted to conclude that intercropping research would hence tend to offer proportionately more benefits for smaller farmers. However, it was found that virtually all of the high-yielding varieties (HYVs) in the six villages were sown as sole crops. To the extent then that new intercropping technology will embrace HYVs, it is not clear that smaller farmers will benefit more. The question remains as to why the HYVs are not intercropped, whereas the local cultivars generally are. Perhaps the HYVs are less risky than the locals and/or they were never evolved or recommended under an intercropping situation. More research is under way to test these hypotheses.

In the villages with more irrigation (Dokur) and/or very deep Vertisols (Shirapur), 60 to 100 percent of the land is planted to sole crops. In Aurepalle, where drought-resistant castor is extensively grown, the proportion of sole cropping is also relatively high - more than 40 percent. It seems from this evidence that the less-assured (in terms of rainfall) areas could benefit more from intercropping research. It also suggests that if improvements in soil- and water-management technologies enhance the resource base and make the environment more stable, one may see more sole cropping practiced. This is because intercropping seems to be primarily practiced as a risk-reducing procedure.

In Kalman Village, as many as 60 different intercrop combinations were grown and 10 to 20 were not uncommon in the other villages (Fig 89). This increased complexity in cropping systems seemed to be associated with a more heterogeneous natural resource base. These have evolved largely through farmers' informal trial-

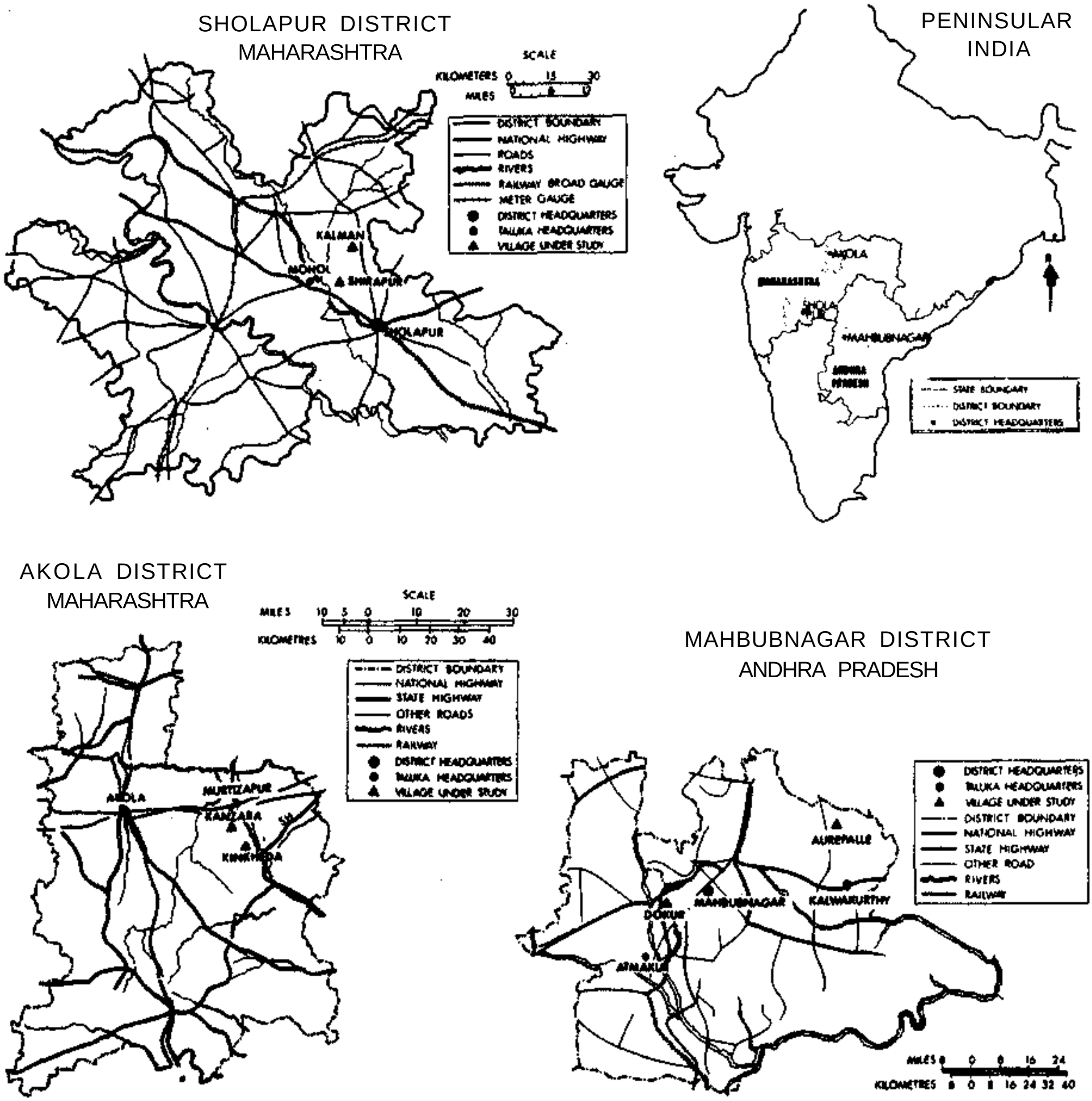


Figure 86. Location of the six villages in SAT peninsular India selected for Village Level Studies.

and-error experimentation and are aimed at satisfying their various needs. Under these circumstances, intercropping research would seem to have its greatest potential contribution if it substantially embraces new technological elements such as HYVs and land- and water-management techniques new to the farmers.

Weed-control Economics

In a study of the economics of weed control practices in six SAT areas of India, it was found the most-frequent and -timely operations occurred in the relatively assured rainfall zone of Akola where cotton dominates the cropping

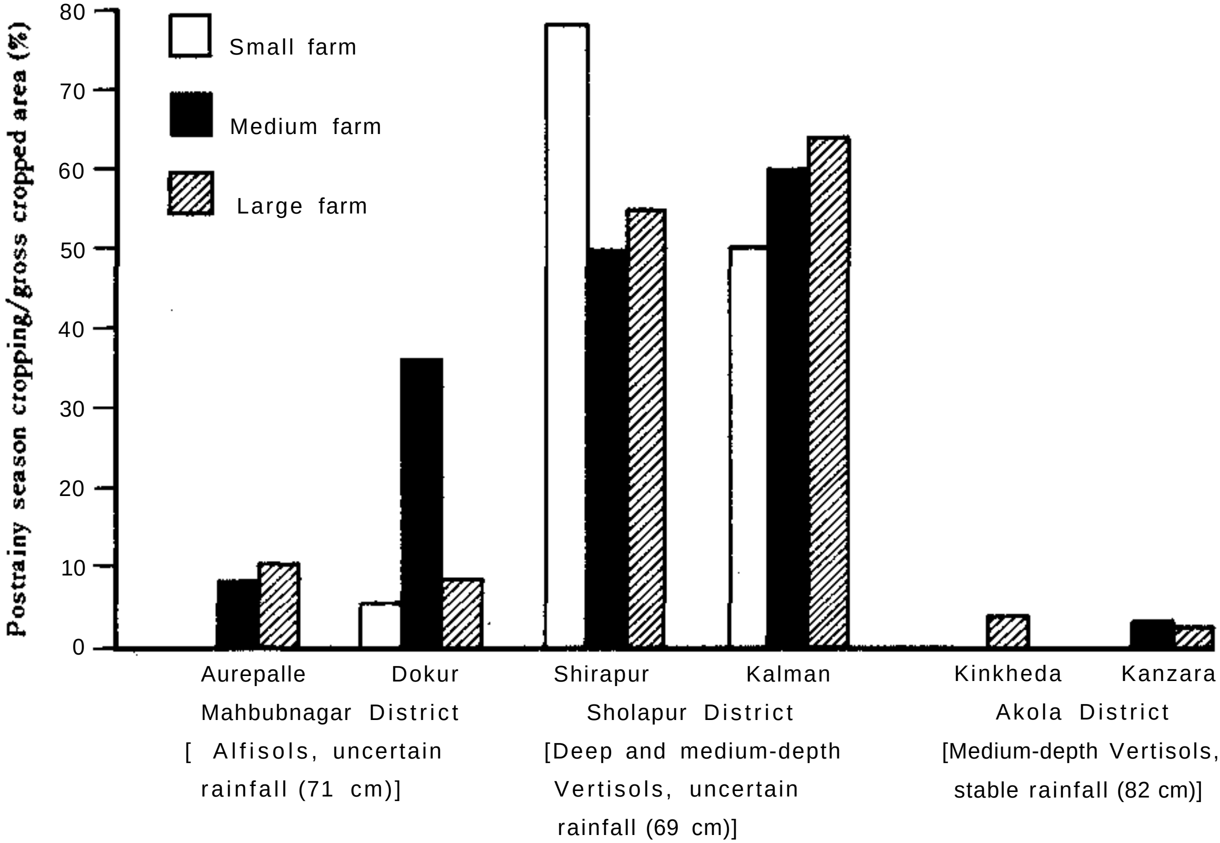


Figure 87. Proportion of postrainy season cropping to gross cropped area in six SAT villages of India, 1975-1976.

system on Vertisols (Fig. 90). Here more than 90 percent of intercrop sorghum fields are intercultivated two or more times. More than 60 percent of the intercultivation operations are initiated within 15 days after sowing. Other crops in Akola follow a similar pattern.

In the Alfisol area of Mahbubnagar, where the rainfall pattern is relatively less assured, weed growth is somewhat less vigorous and rapid. Intercultivation operations are less frequent and are generally initiated 26 or more days after sowing. Little hand weeding is carried out on rainfed crops, and most weed control is given to irrigated or cash crops.

In the deep Vertisols of Sholapur District where postrainy season sorghum is a prevalent crop, little intercultivation and no hand weeding occurs. The single intercultivation performed by most farmers is very much delayed (more than 6 weeks after sowing) and its purpose is to close cracks in the soil for moisture conservation rather than for control of weeds, which appear much less of a problem in postrainy season crops. Several harrowings are performed on fallow lands during the rainy season; these substitute for intercultivation in the postrainy season crop.

The conclusion from the examination of present weed-control practices in the six villages is that, in general, farmers allocate weed-control effort rationally across regions and crops. The higher the crop value and the more vigorous the early weed growth, the more intensive and timely weed control becomes. This indicates that under improved farming systems which embrace HYVs, fertilizers, improved implements, and land and water management, farmers would tend to increase weed-control efforts.

An evaluation was made of the estimated

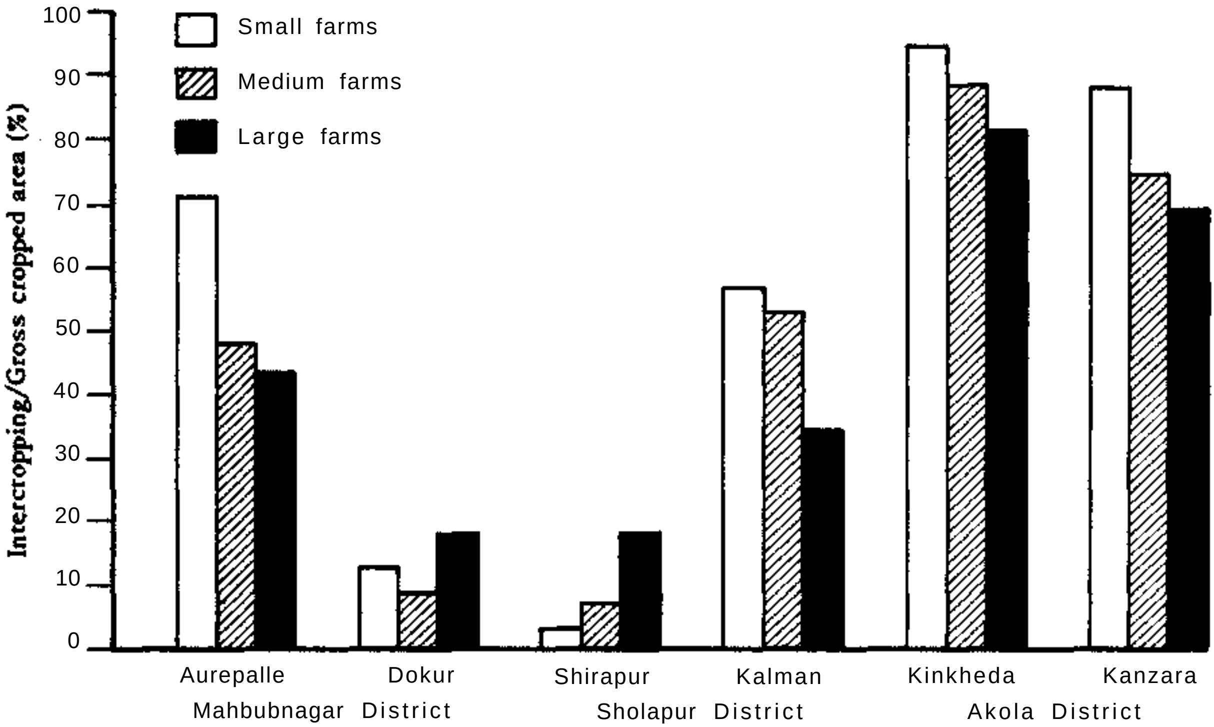


Figure 88. Proportion of gross cropped area devoted to intercropping in six SAT villages of India, 1975-1976.

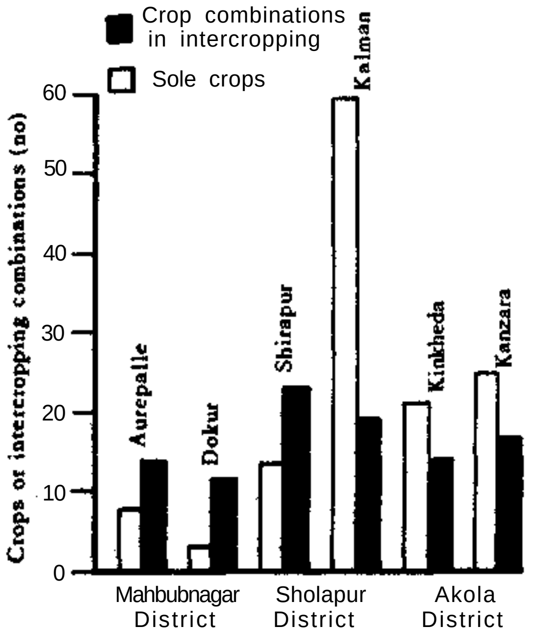


Figure 89. Crop combinations used in intercropping and crops used in sole cropping in six SAT villages of India, 1975-1976.

relative costs of three alternative weed-control practices under conditions existing in the Akola region of Maharashtra. The three plans were designed to achieve about the same level of weed control using (i) human and animal power only, (ii) partial herbicide use plus human labor, and (iii) herbicides only. The cost of the pure herbicide treatment was so high that it could never be feasible at existing wage rates. As Figure 91 shows, for food-grain crops under SAT Indian conditions, even partial herbicide use combined with animal and human methods was two to four times more costly than the traditional animal and human methods. The basic reasons for this are the low wage rates for human and bullock power in India. For small farmers using their own family labor in which the opportunity cost is generally lower than ruling wage rates, there is even less incentive to use herbicides. In SAT Africa, where real wage rates may be two to four times those in SAT India, herbicides may be a more viable proposition.

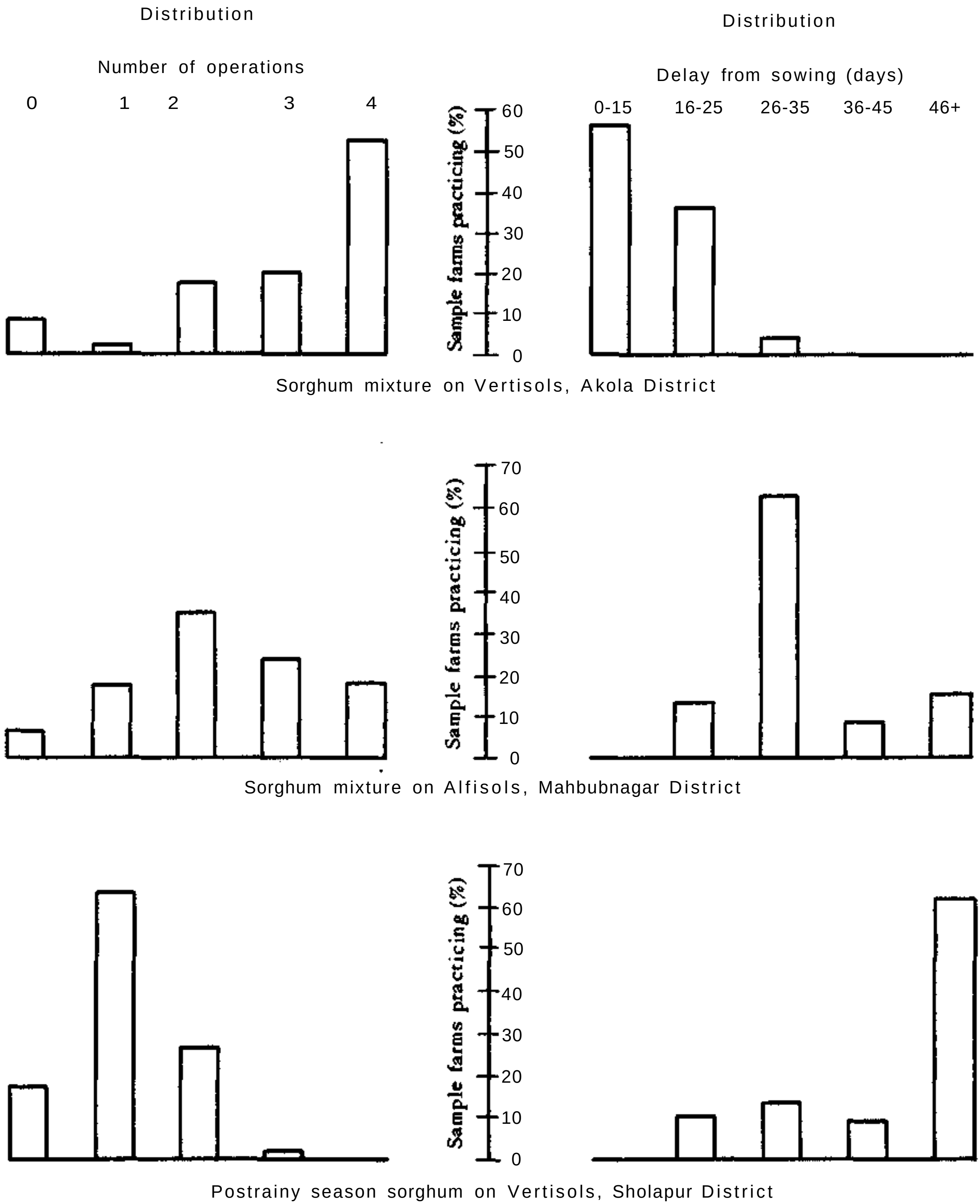


Figure 90. Frequency and timing of weed-control practices on selected rainfed crops in three SAT districts of India, 1975-1976.

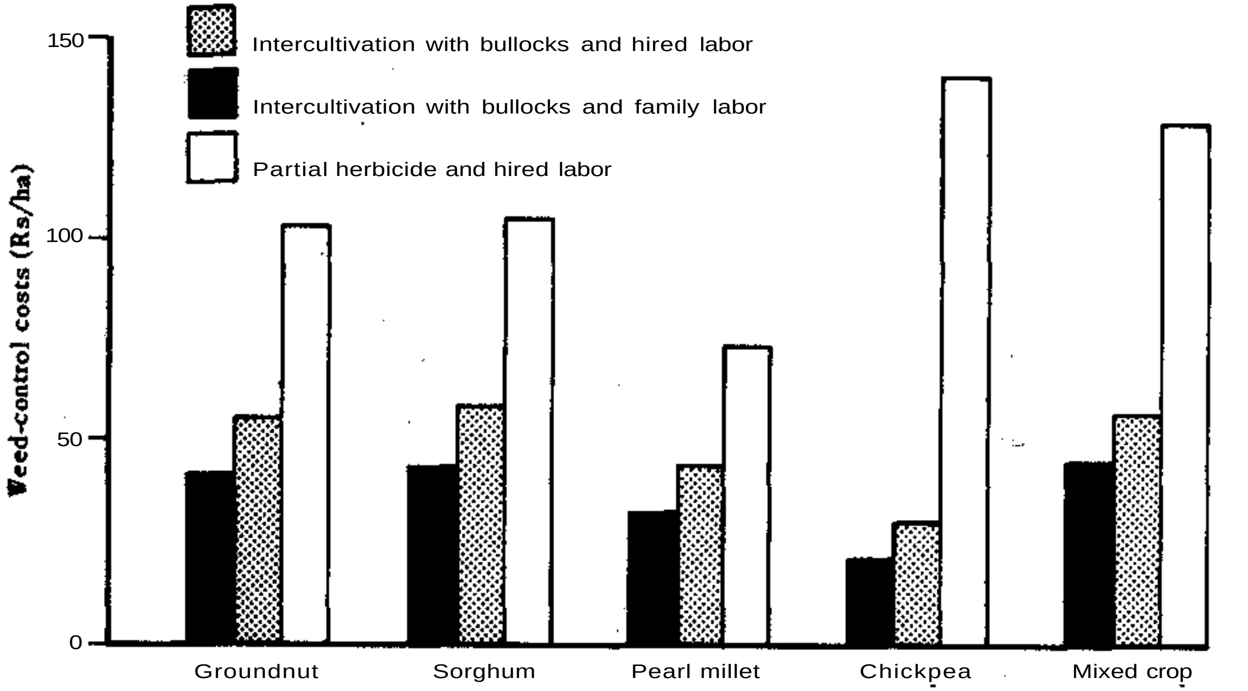


Figure 91. Comparison of costs of alternative weed-control methods in Akola District, Mahara India, 1975-1976.

Unless herbicides make possible substantial yield increments not achievable by traditional methods (such as a preemergence herbicide), then widespread use of herbicides will be out of the question for a long time to come in SAT India. Wage rates would have to rise by more than SO percent to make the partial herbicide plan attractive in pearl millet. For other crops, the wage rise would have to be even more. Real wage rates in SAT India have been stagnant for the past decade or so. Hence such increases are unlikely in the near future.

Herbicide research and technology in SAT India could adversely affect income-earning opportunities of one of the most disadvantaged of all rural socioeconomic groups, namely female laborers, and in particular hired females from landless and small farm households. From 70 to 90 percent of the hand weeding is performed by hired female labor (Table 75) whose wage rates are generally about half those of hired males. The labor displacement that herbicides could cause in SAT India could be substantial, particularly in crops like cotton and sorghum in the assured rainfall areas. The African SAT situation, with its higher wage rates and opportunity costs, may be quite different. Landless laborers are rare in many African areas, and animal power for intercultivation is often not available. Weed-control problems there seem substantial, and would justify a greater allocation of ICRISAT's weed-control research resources than is the case for India.

Group Action and Organization

A review of the extensive economic and anthropological literature on group action and organization, together with an examination of various case studies, revealed that several requirements must be met if group action is to be successful. These requirements are especially relevant in the context of developing and implementing improved land- and water-resource-utilizatioa technologies, where environmental or planning units are often much larger than individual holdings. These conditions also seem helpful in distinguishing the types of technology designs

Table 75. Sex distribution of hand-weeding activity on sample farms in three districts in SAT India, crop year 1975-1976.

	Akola District, Maharashtra		Mahbubnagar District, Andhra Pradesh	Sholapur District, Maharashtra
	Cotton	Sorghum	Groundnut	Sorghum
Handweeding by females (%)	98	96	100	100
Handweeding by hired females (%)	91	77	77	70
Days of weeding wage employment per sample farm[a]	78	24	5	11

[a] Based on 8-hour days.

which require a minimum of outside administrative input and control. Such attributes seem desirable if viable adoption of watershed-based systems is to be ensured.

The conditions necessary for successful group action appear to be:

(i) the resource or activity around which the group forms must be both *collective* and *organizational* in nature - that is, action of all members of the group is required for its creation and the activity is not available unless potential beneficiaries organize themselves to procure or create it;

(ii) the *basic profit* from the group activity must at least equal the rate of return required to motivate private investment, plus a premium or *compensatory profit* to cover the transactions cost of organizing people and of having them forego some of their individual decision-making powers;

(iii) there must be a *functional identity* in the collective good which participants in the group can recognize; that is, the benefits should be distributed so that no one member or group can coerce others to ensure that he or they gain a disproportionate share - or a benefit qualitatively different from that derived by the others; and

(iv) *group size* must be appropriate to ensure its longevity for the tasks at hand. Small groups (5 to 15 farmers) generally appear best for tasks of limited duration, while larger groups (up to 90 to 100 farmers) are suited to longer-term purposes. The smaller the group, the greater are the chances of factionalism and eventual breakdown of the group; the larger the group, the greater are the transactions costs of organizing them to agree. Optimal size is dependent on the technological, economic, and political environment in each situation.

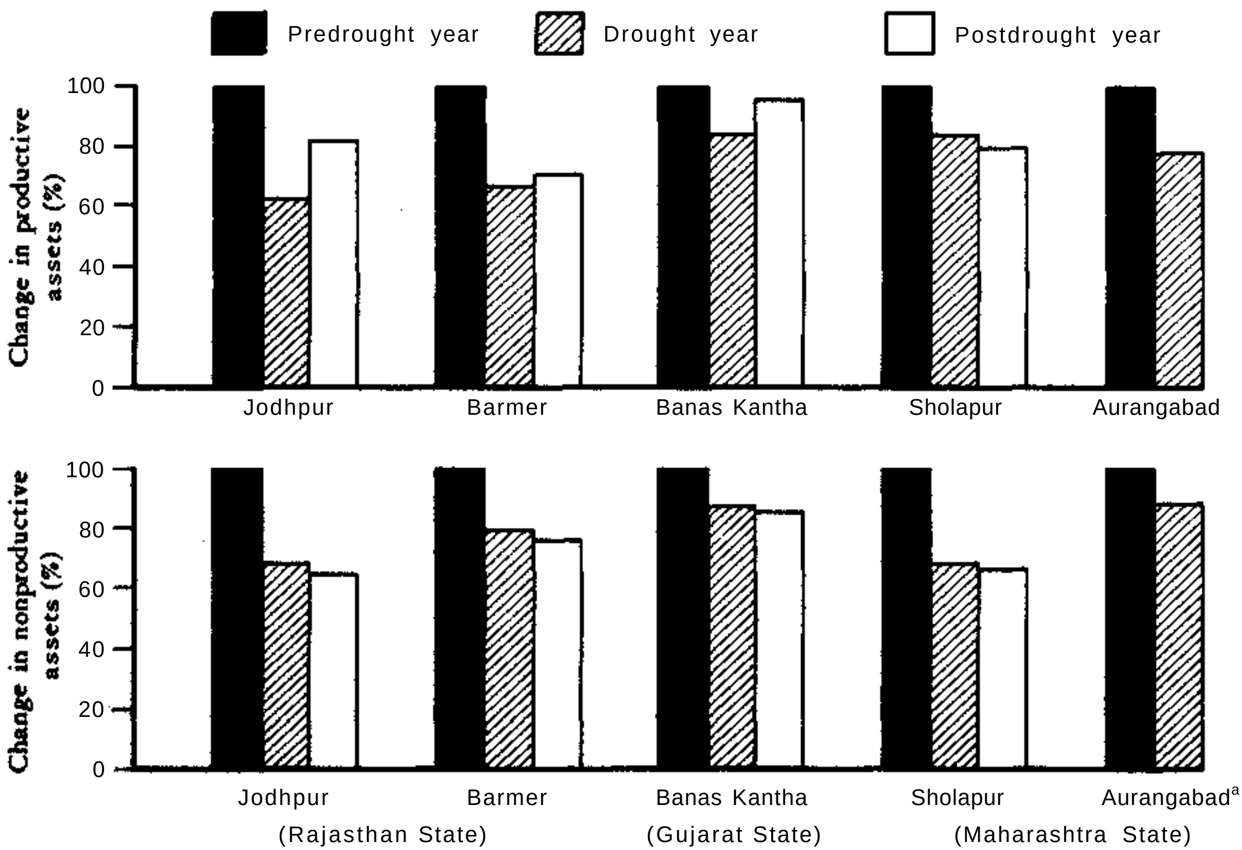
From detailed analyses of case studies of group action - successful and unsuccessful - in India, it seems small groups of farmers could be viable for one-time tasks like land shaping and redistribution of plots such as may be required to implement ICRISAT's watershed-based technologies. Supplementary irrigation out of earthern runoff-collection tanks may require larger groups. However, more research is required to test these hypotheses and to determine whether the above conditions are *sufficient,* in addition to being *necessary,* for successful group action.

Credit and Risk

Data from ICRISAT's village-level studies and studies by others conducted during drought periods in arid and SAT India were analyzed to determine the degree of success farmers have in managing their assets and consumption over drought cycles. The studies include data from two areas of Rajasthan, one in Gujarat, and two in Maharashtra for the drought years 1963-1964, 1969-1970, and 1972-1973.

It was found that the largest reduction in consumption during droughts occurred with ceremonial expenses (40 to 60 %), followed by expenditure on "protective" foods like milk, sugar, fruits, vegetables, and fleshy foods, etc. (30 to 40%). In all except one area, expenditure on education, medicines, etc. fell during droughts by about 40 percent. Despite a relatively unchanged expenditure on food grains, the consumption of food grains fell by 10 to 25 percent during the drought years due to higher food-grain prices.

The value of "productive" assets, consisting primarily of livestock and implements, fell by 15 to 40 percent in drought compared to predrought years (Fig 92). The decline in "nonproductive" assets like jewelry and consumer durables is generally less marked. The "productive." assets are not recouped fully in postdrought years. With the frequency of droughts which occur in these areas, assets may never be recovered to desirable levels before another cycle of asset depletion-replenishment is initiated.



[a] Postdrought data not available.

Figure 92. Changes in household productive and nonproductive assets, because of drought, in five districts of India.

Compared to predrought years, indebtedness increased by 160 to 320 percent in drought years. In three of the four areas (data for Aurangabad was not available), indebtedness increased further after droughts. However, borrowing contributed only between 5 and 15 percent of the sustenance requirements during drought periods (Fig 93). The importance of government relief projects in the sustenance of farmers in drought-prone areas is clearly demonstrated; government relief work provided 25 to 55 percent of sustenance in the various areas. This was followed by migration and remittances from outside (12 to 27 %) and sale of assets (12 to 26 %).

Of the small role played by credit in drought sustenance, it was found that less than 15 percent comes from institutional sources in Rajasthan, whereas the bulk (65 to 80 %) comes from traders and moneylenders. In Gujarat, institutional sources provided about 40 percent of drought credit, traders 30 percent, and relatives most of the remainder. In the Maharashtra villages, most (55%) of the drought credit came from institutions, then from large farmers (25 %), and from relatives (20%). In postdrought years in Rajasthan, the share of credit from money lenders, large farmers, and relatives increased, while that from traders decreased. In Gujarat and Maharashtra, institutional credit substantially increased in importance after the droughts and that of traders and large farmers decreased during this period. In all areas, the proportion of credit in kind rather than in cash increased substantially (from 1:1 to 4:1) during droughts.

This evidence lends support to the thesis that during drought periods credit is primarily used for consumption, while in postdrought periods it is used for crop production and asset replenishment. Cooperatives and banks traditionally do not lend for consumption purposes, and this explains their relatively minor role during the actual drought. Although interest rates can rise by more than 50 percent in drought years (partly due to added risks of consumption loans), private lending agencies seem to offer the required flexibility in terms of repayment which more

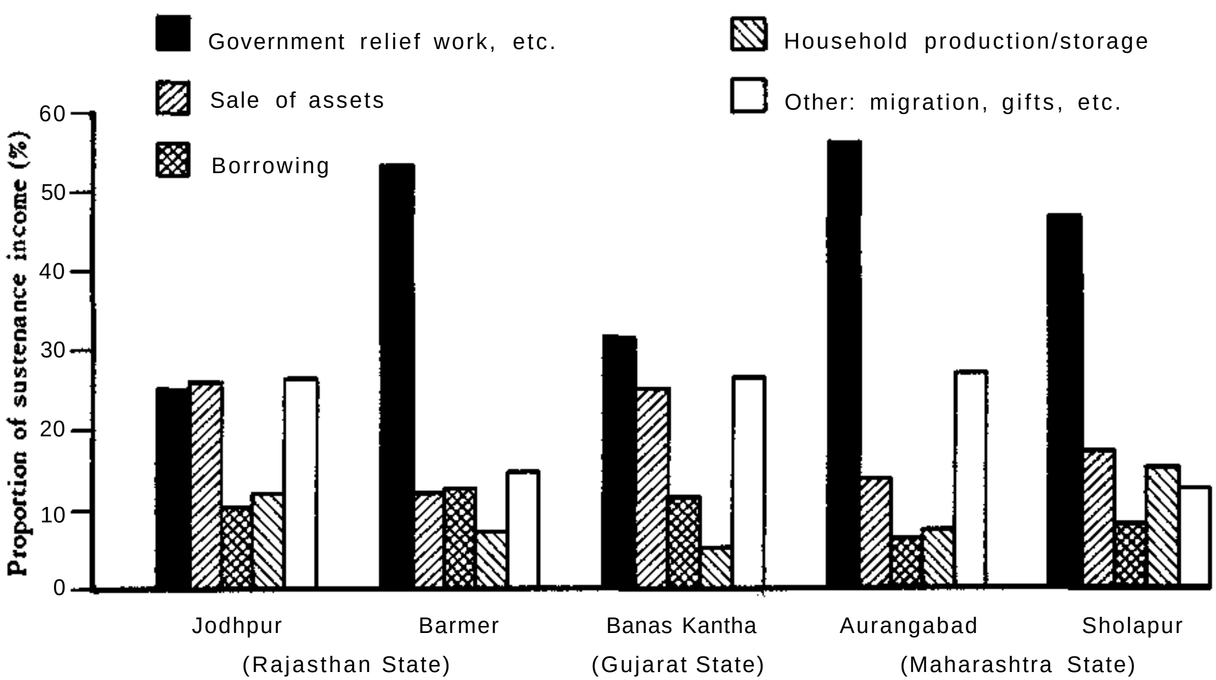


Figure 93. Sources of sustenance income during drought years in selected households in five districts of India.

nearly suit the requirements of borrowers during such times. Links are established between factor and product markets to enable repayments to be made using a variety of vehicles-such as exchange labor, grain, etc. Formal credit agencies could profit by providing more flexibility in repayment terms through integration of credit services with factor markets more explicitly.

Effect of "Green Revolution" in Wheat on Pulse and Nutrient Production in India

High-yielding varieties of wheat were introduced into India in the mid-1960's, and their effect on the production of pulses and major nutrients has been evaluated by ICR1SAT. Linear trend lines were fitted to data from the six major wheat-growing states of India for the 10-year period preceding 1964-1965, and separately for the subsequent 10-year period. The states were Punjab, Haryana, Uttar Pradesh, Bihar, Rajasthan, and Madhya Pradesh. It is apparent that 22 percent of the expansion in wheat hectarage which occurred in the latter period could be accounted for by reductions in the area sown to pulses, particularly chickpeas. Eight percent of the expansion in wheat came at the expense of winter rice and barley. The vast majority of the growth in area sown to wheat in the six states was due to increases in cropping intensities resulting from the HYVs and the expansion in irrigation, and an increase in net sown areas.

Total annual trend food-grain production in 1974-1975 in the six states would have been 13.4 percent less, had HYVs of wheat not been introduced. This takes into account the reduction in production of pulses, winter rice, and barley, as well as the increased wheat production. The following percentage reductions would have occurred in *total annual* 1974-1975 production of various nutrients: protein, 10.0; energy, 13.5; methionine and cystine, 15.5; tryptophan, 11.3; leucine, 5.9; and isoieucine, 2.0.

Per-caput production of food grains and the above nutrients would also have been less had HYVs of wheat not been introduced. Generally, the per-caput reductions would amount to between 1 to 2 percentage points less than the above figures. Total lysine production would have been about 6.4 percent more had HYVs not been introduced. Calories, rather than protein or amino acids, seem to be the first limiting nutrient in the diets of most Indians (including those in the least affluent socioeconomic categories). Vitamin A and vitamin B complex, calcium, copper, iron, and zinc follow. The small reduction in lysine is hence an acceptable price to pay for the substantial increases in production of food grains, energy, and protein resulting from use of the HYVs. When the record production year of 1975-1976 is compared with projected pre-green revolution trends, the production of all nutrients, including lysine, shows a substantial increase over what would have occurred had pre-green revolution conditions continued. The percentage increases in 1975-1976 nutrient production as a result of the green revolution are estimated to be as follows: protein, 20.1; energy, 21.9; lysine, 6.9; methionine and cystine, 20.9; tryptophan, 32.5; leucine, 16.2; and isoieucine, 12.1.

Even though the prices of chickpea relative to wheat have risen since 1964-1965, the real prices of protein and energy from both sources has substantially fallen. For chickpea, the real prices of protein and energy have fallen more than 20 percent between 1964-1965 and 1974-1975. For wheat the reduction has been more than 33 percent. Every hectare of 1974-1975 wheat which substitutes for a hectare of chickpea also adds a further 55 kg of protein and 2527000 kilocalories of energy to what the chickpea would have produced.

Hence, it is clear that the net nutritional impact of the new HYVs of wheat introduced in the mid-1960's in India was both positive and substantial. The success of these wheats clearly illustrates how a plant-breeding strategy which emphasizes increased yield potential can result in significant improvements in aggregate nutritional well-being.

Breeding strategies which emphasize yield and yield stability offer the best prospects for improving nutritional well-being of the least nutritionally and economically affluent groups in the SAT. Increased yields and production of food grains has a direct impact on prices and real incomes of the least-affluent groups, who spend a large amount of their incomes on food grains. Increased real income will enable them to purchase additional food grains and hence improve their nutrition. If yield potentials of cereals, pulses, oilseeds, and other crops could all be substantially increased, nutritional improvements will follow as these all have complementary nutritional compositions. It is not necessary that any one of the grains have a "balanced content" of all nutrients — which is the underlying premise of cryptic quality breeding programs. People eat more than one food item each day. Making available additional quantities of all foods is the appropriate nutritional strategy. Nutrition education can help ensure that the correct mix is consumed. It is unreasonable to expect any one grain to provide a balanced diet.

Marketing Economics

Market Surpluses of Food Grains

Access to markets provides a primary incentive for farmers to adjust farm organization and cropping patterns to capitalize on the comparative regional advantages in production of various enterprises. A study of the research literature and published data on market participation by Indian food-grain producers showed that the bulk of production does not reach formal market channels. The proportion of production which reaches the market varies across regions, crops, and years. Two factors seem to consistently influence household marketed surplus (production minus quantities retained for consumption). Generally the larger the farm production of food grains, the larger the amount of marketed surplus. On the other hand, as family size increases, the amount of farm food grain marketed tends to fall.

Table 76 shows that the official estimates of sorghum arrivals in Indian assembly markets as a proportion of 1972-1973 production are around 14 percent. For chickpea they are around 26 percent. Increases in production in subsequent years, together with relaxation of interstate and intrastate trade restrictions, leads us to believe market arrivals may have increased. ICRISAT's "educated guesstimate" of current market arrivals for sorghum and millets is around 15 to 20 percent, while for chickpea and pigeonpea it is between 35 and 40 percent.

Chickpea has shown a strong upward trend in arrivals at regulated markets since 1969-1970 (Fig 94). Arrivals of rice and groundnuts have been relatively steady, while wheat, millets, and sorghum showed increases between 1969-1970 and 1972-1973, followed by downward trends.

World Sorghum and Millet Trends

World demand for coarse grains in the year 2000 is estimated by the World Food Council to be double or more the demand experienced in 1970. About one-fifth will be for direct human consumption and four-fifths will be fed to animals. In the LDCs (less-developed countries), demand for coarse grains is expected to triple by the year

Table 76. Market arrivals (as a proportion of production) of wheat, rice, sorghum, and chickpea from villages to assembly markets.

Year	Wheat	Rice	Sorghum	Chickpea
	(%)			
1960-61	20	NA[a]	NA	NA
1966-67	20	NA	NA	NA
1967-68	24	NA	NA	NA
1968-69	29	22	13	27
1970-71	31	26	13	27
1972-73	31	24	14	26
1974-75	25[b]	24[b]	1[b]	35[b]
1976-77	30[b]	25[b]	17[b]	37[b]

Source: Indian Agriculture in Brief, 9th, 10th, 12th, 13th, and 14th editions. Directorate of Economics and Statistics, Ministry of Agriculture, Government of India.

[a] Data not available.
[b] ICRISAT estimates.

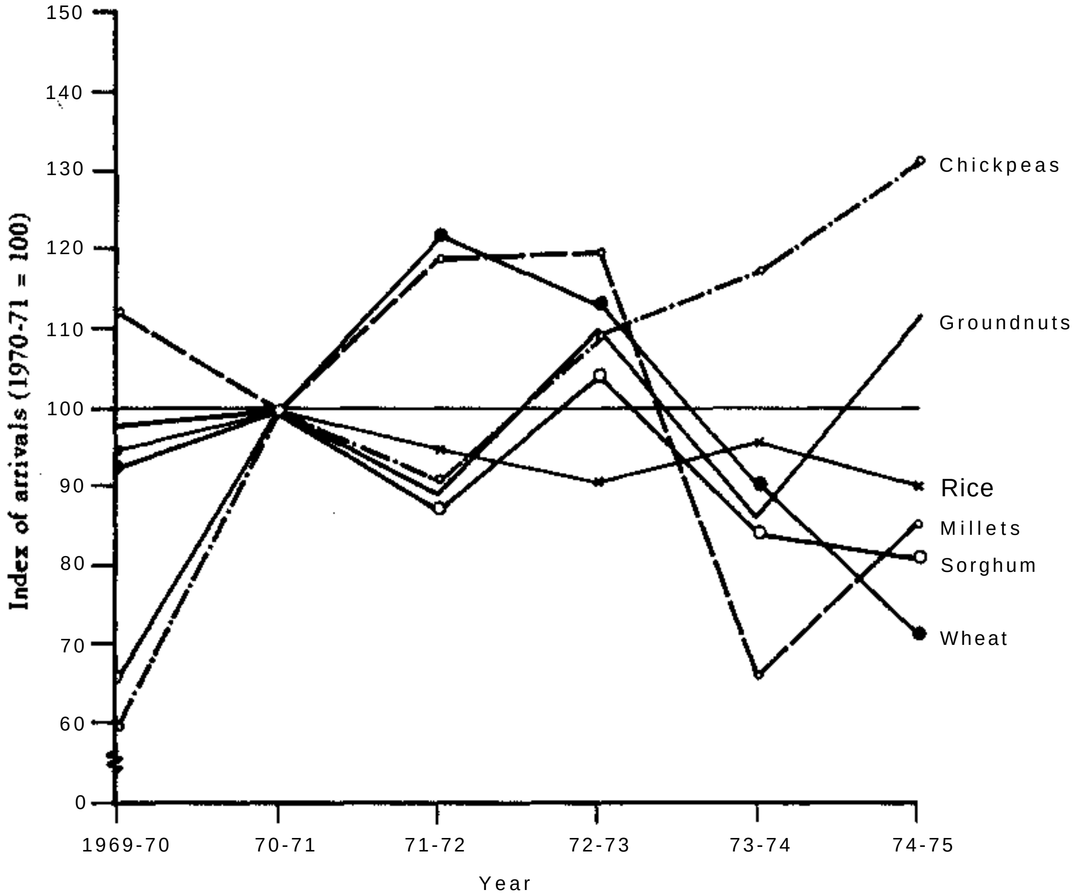


Figure 94. Index of market arrivals of major food grains in selected regulated markets.

2000. Some 60 percent will be for human consumption.

Comparing the projected annual compound growth rates of demand for coarse grains, using World Food Council data, with past annual trend growth rates of sorghum and millet production from 1964 to 1974, a picture of excess-demand imbalance emerges for the LDCs (Table 77). Demand for coarse grains in the LDCs is estimated to grow 3.23 percent per year while, historically, production of sorghum and millet has grown by only 2.13 percent. The past production growth rate in LDCs of the SAT has been even less than this -2.11 percent per year. The picture for the developed countries shows an excess-supply position emerging, with an annual demand growth of 2.14 percent and past production increasing at 3.48 percent. Hence the projected future overall world supply-demand balance for coarse grains seems favorable. If trade flows permit the excess production in the developed countries to move to the grain-deficient LDCs, then their position will be improved.

About 80 percent of the world's sorghum area *(Sorghum vulgare, S. Sudanese,* and *S. almum*) is located in LDCs of the SAT, but the production from this area represents only 60 percent of the world's total output. Since 1964 the area devoted to sorghum by these countries has increased by 235 000 hectares per year, but the increase has mainly been in Africa (south of the Sahara), Mexico, and South and Central America. In SAT Asia, the sorghum area has declined and yield

Table 77. Projected demand and past trends in coarse-grain production.

Region	Annual projected compound increase in demand for all coarse grains	Annual trend compound increase in sorghum and millet production, 1964-1974[b]
	(%)	(%)
LDC (in SAT) market economies	NA[c]	2.11
LDC (non-SAT) market economies	NA	2.37
Total - LDC market economies	3.23	2.13
Total - Developed countries market economies	2.14	3.48
World	2.41	2.50

[a]Source: Aziz, Sartaj. "The World Food Situation Today and in the Year 2000". Paper presented at World Food Conference, 1976, Iowa State University. (Dr. Aziz is Deputy Executive Director, World Food Council).
[b]Calculated by ICRISAT from data contained in various editions of the *FAO Production Yearbook.*
[c]Data not available.

trends have also been relatively stagnant, increasing (on a hectare basis) only 14 kg/year. This increase is much less than that in other areas, where sorghum is used primarily for animal feed.

World sorghum production increased from a trend value of 37.6 million metric tons in 1964 to 51.3 million in 1974 (Fig 95), representing an annual trend increase of 1.37 million tons. Production has risen fastest (360%/year) in SAT LDCs of South America, followed by Australia (a developed SAT country) at 223 percent per year.

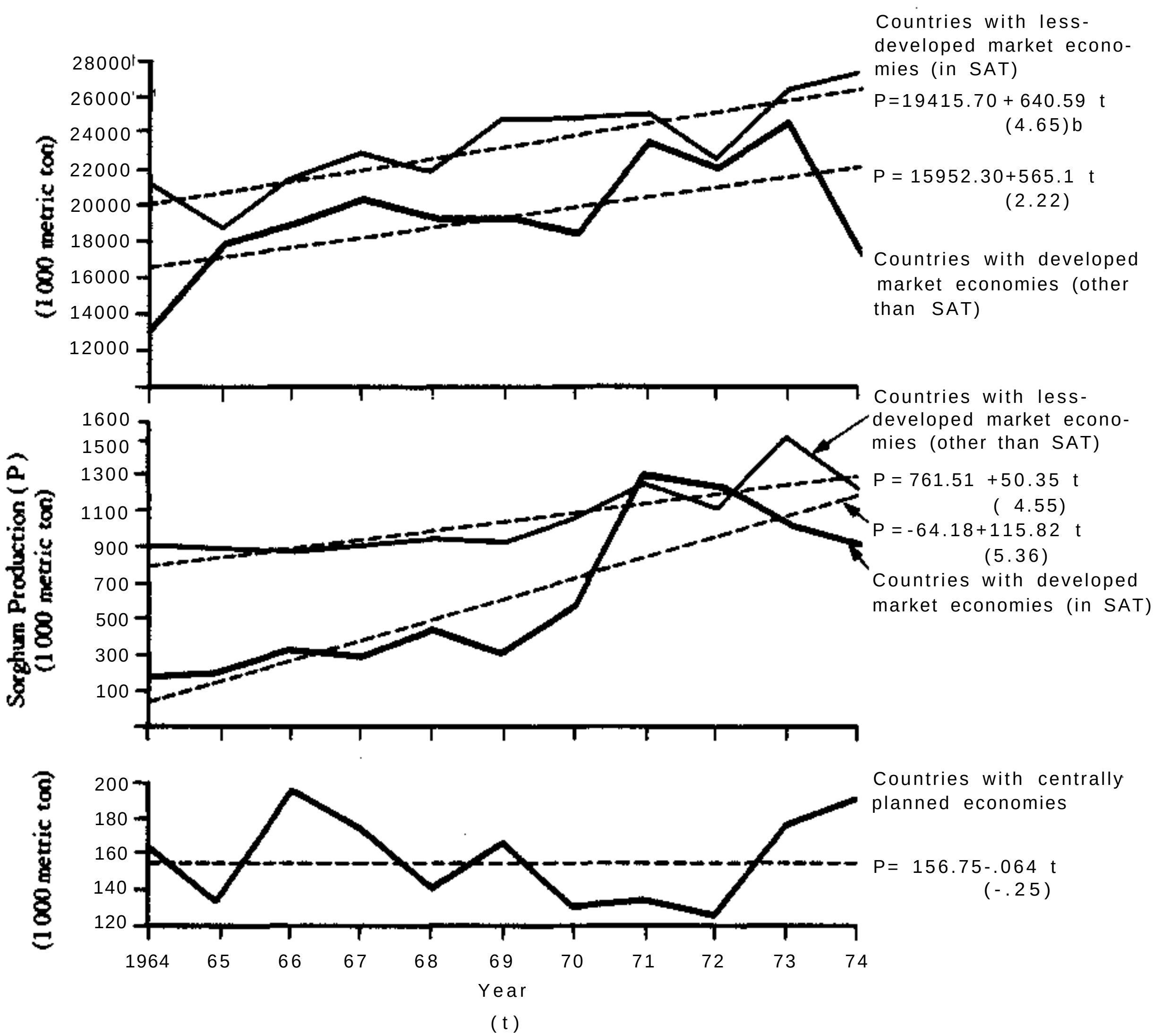
There has been little change in the world area of millets *(Pennisetum americanum, Eleusine coracana, Panicum miliaceum, Setaria italica,* and *Echinocloa crusgalli*) since 1964. The 68 million hectares of millets grown in the world is shared about equally between the People's Republic of China (and other centrally planned economies) and LDCs in the SAT. Approximately half of the world's millet area is devoted to the *Pennisetums. Setaria* occupies about 23 percent, *Panicum* 14 percent, and *Eleusines* 8 percent.

Unfortunately, the two major millet-growing regions in the world have the lowest yields. Yields have been rising by 17 kg/ha annually in the centrally planned economies, where *Setaria* is the principal species. Yields in the SAT LDCs (where *Pennisetum* predominates) have been rising only about 6 kg/ha each year.

In the countries with centrally planned economies, total millet production has been increasing by about 600 000 tons per year since 1964 (Fig 96). In the SAT LDC areas, millet production has been rising by around 200000 tons per year. World millet production amounts to about 47 million tons annually. It has been increasing by 800000 tons per year. Apparently some 85 percent of the world's millet is used for human consumption.

Sorghum and Millet Trends in India

On the basis of secondary data it was shown that, in India, up to a monthly per-caput income level of around Rs 15, the per-caput consumption of coarse grains increases, reaching a peak of just



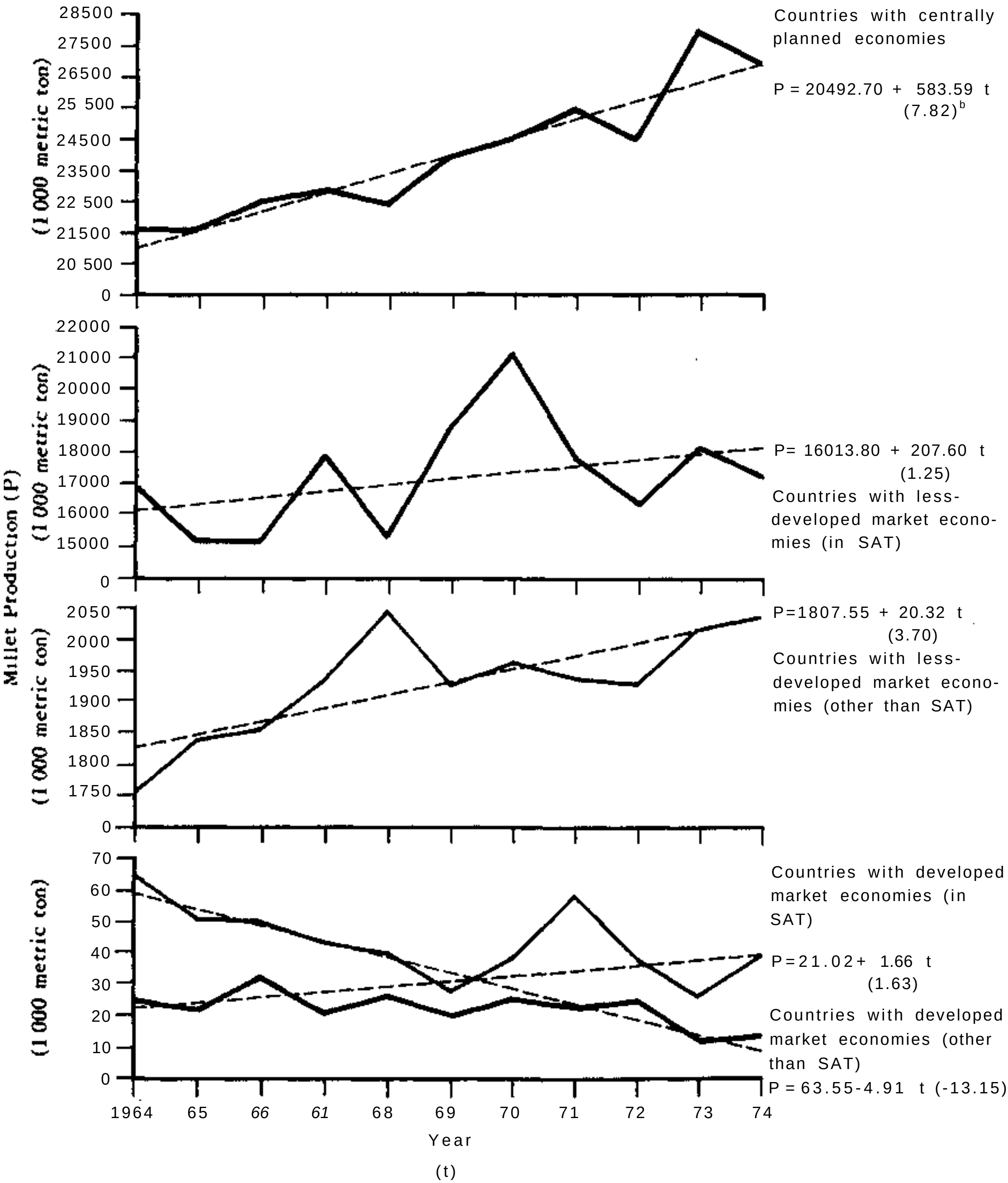
[a]Equations represent linear trend lines fitted by ordinary least squares regression analysis.

[b]Figures in parentheses are t-values.

Figure 95. World sorghum production trends.

less than 7 kg/month. At higher income levels, per-caput consumption declines. About SO per-cent of India's population has a monthly income of less than Rs 15. Hence, population and income growth in India will continue to place heavy strains on demand for coarse grains.

Growth in coarse-grain production in India has not kept pace with demand during the last 20 years despite introduction of HYVs. In 1971, production was estimated to have fallen behind demand by 1.7 million tons. If these trends continue, the shortfall could be around 4 million tons by 198S. To meet this from local production will require an annual production growth of 3.2 percent per annum. It seems if this increase is to be achieved, yields per hectare must rise as land for expanding the area under coarse grains is very limited.



Equations represent linear trend lines fitted by ordinary least squares regression analysis.

Figures in parentheses are tavalues.

Figure 96. World millet production trends.

Interregional Trade and Welfare

Spatial equilibrium models were used to explain the potential contribution of improved market channels and trade on cropping patterns, aggregate productivity, and the welfare of consumers and producers. Examples of rice, sorghum, and chickpeas grown in Andhra Pradesh, Madhya Pradesh, and Maharashtra were selected for study.

Results suggested that if trade in food grains were restricted to 10 percent of "free-trade" levels, food-grain production would be about 2 percent less in these three states. Most of the reduction would occur in chickpea, and to a lesser extent in sorghum (Table 78), because regions would be prevented from concentrating on crops for which they have a comparative advantage.

Relative prices of food grains would be also markedly affected by trade restrictions. For example, prices of the three grains would fall in Madhya Pradesh (Table 78). This would mean substantial reductions in the production of the three crops in that state. In Andhra Pradesh, chickpea prices would rise by about 140 percent. Prices and production of rice in Maharashtra would rise and for chickpeas they would fall. This illustrates how restrictive trade policies can encourage production of crops in areas where the crops do not have a comparative advantage, and away from those where they do grow comparatively well.

Pulse production in India has declined substantially in recent years. The analysis above illustrates how food policies could be used to enhance pulse production and help arrest this trend. In the process, welfare of consumers and producers as a whole could be improved. However, the distribution of these welfare gains would differ amongst the states and between consumers and producers.

Looking Ahead in the Economics Program

In the Economics Program, we expect -

— to continue our village-level studies in southern India for a further year or two, and to extend them to include areas in northern India and Africa;

— to develop simulation models which can help evaluate the potential for water harvesting and supplementary irrigation on different crops in different agroclimates;

Table 78. Estimated price and production changes resulting from food-grain trade restrictions in three states of India.

	States						
	Andhra Pradesh		Madhya Pradesh		Maharashtra		
Crops	Price	Production	Price	Production	Price	Production	Overall Production
	(Change in %)						
Rice	-8	-1	-34	-5	+68	+29	+1
Sorghum	-38	-4	-37	-7	+38	-4	-5
Chickpea	+143		-61	-17	-62	-22	-13

[a]From zero production in the unrestricted case to only 44000 metric tons.

- to identify necessary conditions required for successful group organization and action for improved land and water management based on the watershed concept and to initiate socioeconomic experiments to test if these requirements are sufficient for sustained adoption;

- to develop techniques to assess importance of inclusion of risk-reduction characteristics in new technologies;

- to have quick screening methods for selecting grain-types preferred by consumers;

- to identify market constraints to increased food-grain production in the SAT;

- to have identified more precisely human nutritional needs in the Indian SAT and ICRISAT's role in improving nutritional status.

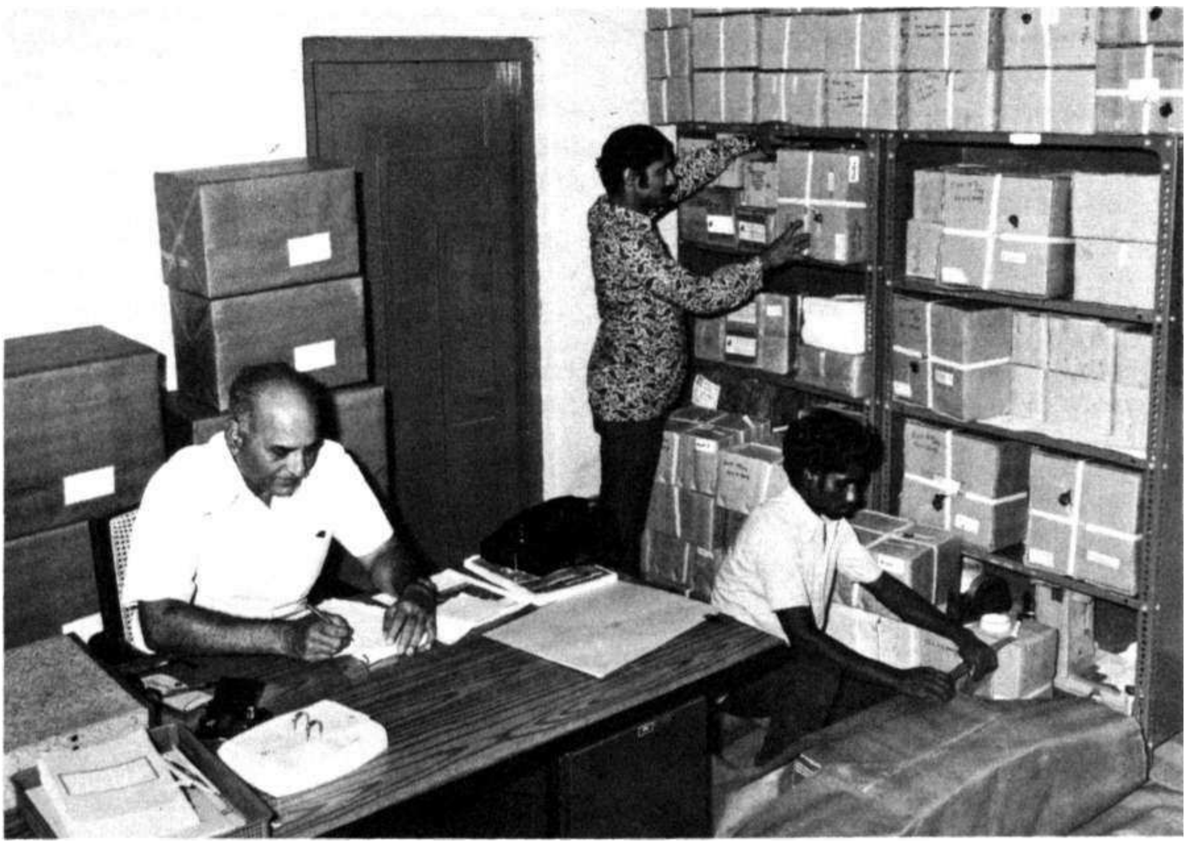
Cooperative Programs

Since its founding, ICRISAT has been committed to the important and fundamental task of assisting the SAT countries of the world increase their food-production capabilities. As rapidly as research programs were developed and plant material and technological information beca'me available at ICRISAT Center, steps were taken to initiate programs of cooperation and assistance with the national research programs in SAT countries internationally. Initially, the programs were limited to the provision and exchange of germplasm of the ICRISAT crops and to short-term consultancies from senior staff. Building on this, a second phase of assistance has evolved which provides various forms of training to candidates from SAT countries and includes posting of ICRISAT scientists to selected sites in SAT countries to undertake research programs of a regional nature as well as to assist in national programs.

West African Cooperative Project

In January 1975, ICRISAT and UNDP entered into a 3-year contract which had as its prime objectives cooperation with and strengthening of existing West African agricultural research programs to develop improved higher-yielding vari-

Figure 97. An important aspect of cooperation with crop scientists all over the world is exchange of germplasm samples and seed. During 1976-1977, more than 38 000 samples were despatched to scientists in more than 70 countries.



eties of sorghum and millet that provided consistent and reliable yields, and the transfer of new technology on crop-production systems. Training of candidates from the region was also recognized as vitally important. The drought-stricken Sahel area below the Sahara was the focus of concern; sorghum and millet are the staple foods of the majority of the people in this area and the food-population balance has been and continues to be seriously strained. The countries making up this region are Senegal, Gambia, Mauritania, Mali, Upper Volta, Ghana, Togo, Nigeria, Niger, Benin, Chad, and Cameroon-a total of 12 in all.

The strategy for implementing an effective program of assistance, which would have an early and measurable impact, was outlined. Basically, the concept was to post ICRISAT scientists to existing research institutions at Bambey, Senegal; Samaru, Nigeria; Kamboinse, Upper Volta; and Maradi, Niger. These scientists would be linked to and would work in conjunction with ICRISAT headquarters in Hyderabad, other ICRISAT cooperating centers internationally, and other national programs in the region as well as program of the host country. Subsequently, in 1977, the contract was expanded to include Sudan with ICRISAT scientists headquartered at Wad Medani. Additional support from other agencies such as Ford Foundation, USAID, and the Dutch Government has provided for additional scientists at Bamako in Mali and Kambomse in Upper Volta.

Implementation of the program has continued to gain momentum and has become fully operational for the 1977 crop year. The total team of 14 scientists is now in place. The major start-up capital items (buildings, plot, equipment, and vehicles) have been constructed or purchased and each component within the network is ready to contribute to the overall objective of assisting the small farmer to increase his food production.

Project manager. The project manager was deputed to ICRISAT by IRAT in July 1975. He has established an excellent regional office in Dakar, Senegal, from which he provides the management and supervision of the overall project and maintains close liaison with all agencies that work on programs of assistance in the region. Recently a French-English translation service has been added to the office and much of the excellent relevant research information previously available only in French is being disseminated to English-speaking scientists as well.

Senegal. During the year, a millet breeder and sorghum/millet entomologist were posted to the Bambey Research Station and areas of responsibility were outlined in collaboration with the Station Director and scientists. It was agreed that the millet breeder would be involved in three types of activities - (i) assisting the national program through introduction and evaluation of the best ICRISAT Indian and East African materials for testing, crossing, and further selection of superior types; (ii) setting up coordinated regional trials in Senegal, Mali, Mauritania, and Gambia, involving the most promising material from all the West African countries; and (iii) providing to the core program at ICRISAT Center the improved germplasm selected from local and regional trials in Senegal and elsewhere in West Africa. This material is then evaluated in further breeding programs and international trials. During the off season several nurseries were grown under irrigation and a substantial beginning was made toward these objectives.

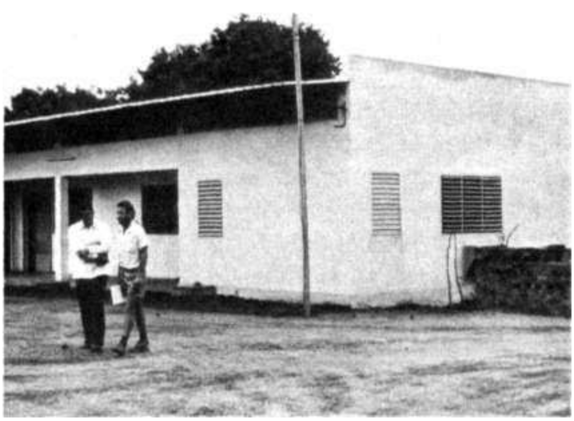
The entomologist will undertake national, regional, and international responsibilities with major emphasis on sorghum pests. Initially, the most serious insect problems in the region must be identified in order to determine the approaches whereby short- and medium-term research is likely to be most fruitful. The economic importance of the wide variety of pests is to be established through observations in farmers' fields as well as through controlled plot experiments at Bambey. Screening of ICRISAT and local material for various insect resistances is an integral part of the program.

Mali. An agronomist-selector joined duty at the Sotuba Research Station in April 1976 and carried out the first set of ICRISAT screening, yield, and agronomic trials during the year, utilizing six widely separated locations within the country. The primary focus was on screening sorghum and millet nurseries, supplied by the core programs at ICRISAT, for local adaptability as well as to determine potential intercropping practices and fertilizer responses. Close collaboration was established with the national scientists and IRAT personnel as well as with the USAID-sponsored "Operation Mil" project at Mopti.

Upper Volta. In 1975 and 1976 a sorghum breeder and plant pathologist respectively were appointed to assist the national sorghum improvement program and to initiate ICRISATs regional effort in that area. In 1977 a millet breeder and two agronomists were added to the team. Major emphasis is placed on developing photo-insensitive, shorter-cycle, medium-height varieties of sorghum and millet capable of withstanding drought conditions at higher plant populations. Initial screening of large numbers of nurseries from ICRISAT Center for disease and insect resistance and general adaptability was conducted and promising materials are available for multi-locational testing throughout the region in 1977. Several very promising lines of sorghum having good levels of disease and insect resistance and potential high yield under stress conditions were identified. A limited testing program on hybrid sorghum also revealed a good potential for the immediate transfer of Indian hybrids to West Africa, although there was evidence that hybrid seed from Indian parents might be more difficult to produce in the West African regions. A number of on-farm trials and demonstrations, featuring improved varieties and cultural techniques, were carried out in collaboration with farmers in Upper Volta. Expressions of interest by increasing numbers of small farmers reflect their appreciation of this effort.

With the addition of a full-time millet breeder, the limited program (previously carried out as an adjunct of the sorghum-improvement research) will be expanded significantly and will follow the general broad research objectives as for sorghum. Similarly, in 1977 agronomy experiments will be introduced. The initial effort will be directed towards developing techniques that will be within reach of the average small West African farmer. Such techniques will aim at utilizing the natural environment as much as possible without relying heavily on chemicals and other inputs. Studies on the interaction between cereals and legumes as intercrops and in rotation, crop-residue management and its effect on percolation and retention of rain water, population densities in sole and intercropped stands, etc., will form a part of this program.

Figure 98. ICR1SA Ts laboratory and office building constructed at the research station in Kamboinse, Upper Volta.



Niger. In 1977 a pearl millet breeder was posted to the Tarna Research Station to work jointly with the national program on millet improvement and to expand ICRISAT's regional research network on this major food crop. Close collaboration with scientists in the region, particularly in Upper Volta and Nigeria, will be maintained. Emphasis will be placed on breeding higher-yielding drought-tolerant shorter types of plant that will be resistant to diseases and pests and will grow well in higher plant densities.

Nigeria. A plant pathologist to work on the diseases of millet and sorghum was appointed in 1977 and headquartered at the Institute for Agricultural Research at Samaru. He will assist the pearl millet breeder appointed there a year earlier. A season of crossing and testing has been completed. Materials supplied by ICRISAT Center as well as those available locally and elsewhere in the West African region were studied. The trials contained synthetic progenies, composites, experimental varieties, adaptation entries, hybrids, and inbreds. Selections were made on the basis of adaptability, uniformity, yield, and resistance to disease and insects.

East African Cooperative Programs

Sudan. Following discussions held in late 1976 by the Government of Sudan, UNDP, and ICRISAT it was agreed that an expansion of the UNDP/ICRISAT West African program to include cooperation with Sudan on sorghum and millet improvement would be in the overall best interests of all concerned. Subsequently, a sorghum breeder and a millet breeder were recruited and stationed at the Agricultural Research Corporation headquarters at Wad Medani. These scientists will work closely with the national programs on these crops and at the same time accept a regional responsibility as an East African extension of the total ICRISAT research network. A great deal of plant material from ICRISAT Center as well as that obtained locally and elsewhere in Africa will be tested in the first year. A total of eight millet nurseries and seven sorghum nurseries are planned-these will include exotics, segregating populations, and advanced yield trials. An ambitious crossing program is also envisaged.

Tanzania. A proposal for a sorghum and pearl millet improvement program for Tanzania-to be operated in collaboration with the Government of Tanzania, IITA, and USAID -has been under active discussion for some time and is expected to get under way by posting a plant breeder and agronomist at the Ilonga Research Station before the next crop year. Tanzania has expressed renewed interest in increasing its production of sorghum and millet and the major objectives would be to develop varieties and methods of culture which will give improved and more-stable yields, better grain 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 - which include *Striga,* birds, shoot fly, and stem borer.

Ethiopia, Kenya, Uganda, Somalia. ICRISAT collaborated closely with these countries by supplying and exchanging germplasm and various nurseries, including advanced lines of appropriate ICRISAT crops, for further testing and selection within national programs. A number of scientists from these countries visited ICRISAT Center and scientists from ICRISAT visited many of these trials. Close working relationships have been established. ICRISAT is continuing to explore possibilities for strengthening of cooperative work on breeding high-altitude, cold-tolerant sorghum for the region.

Southern Africa

The network of ICRISAT cooperative centers continued to expand during the year to include Botswana and Lesotho. Scientists from these countries visited ICRISAT and have been supplied with seeds of appropriate crops as requested for incorporation into their crop-improvement programs.

South American Cooperative Program

Brazil. There was a marked increase in collaboration between Brazil and ICRISAT, including exchange of sorghum and millet materials, exchange visits by scientists, and training and workshops. ICRISAT scientific teams visited the SAT region of Brazil twice during the year - the first team consisting of four scientists and the second team of five. Attention focused in the direction of sorghum and millet crop improvement, land and water management, intercropping, and selection and development of a research station representative of the major SAT areas of the Brazilian northeast. Three Brazilian scientists visited ICRISAT Center to become familiar with the Institute's ongoing programs. One attended the International Sorghum Workshop. A research fellow was brought to ICRISAT Center for a 2-month training session in Agroclimatology.

Cooperation with CIMMYT

Responsibility for the high-altitude cold-tolerant sorghum-breeding program introduced by CIMMYT in Mexico was turned over to ICRISAT, with CIMMYT still providing the facilities and logistic support for its continuation. Reciprocally, ICRISAT is providing a similar service to the CIMMYT Asian Maize program now based at ICRISAT Center.

Asian Cooperative Programs

ICRISAT continued to strengthen its ties with a number of countries in Asia during the year. A large number of trials of the various crops were supplied to Pakistan, Bangladesh, Sri Lanka, Burma, Thailand, Afghanistan, and Nepal, and senior scientists from headquarters visited several of these countries for follow-up discussions and observations of the growing nurseries. A formal working agreement between the Pakistan Agricultural Research Corporation and ICRISAT was finalized to permit a more direct flow of scientists and materials between institutions.

India. A formal Memorandum of Understanding has been signed with the Indian Council of Agricultural Research for all cooperative programs with ICAR Institutions programs and Agricultural Universities in India. Under this agreement, in the meetings of the Joint Advisory Committee, the cooperative programs of mutual interest are discussed.

Based on the suggestions of the Policy Committee, the Government of India has been requested to authorize ICRISAT's setting up research substations at Bhavanisagar (Tamil Nadu Agricultural University, Coimbatore), Dharwar (University of Agricultural Sciences, Bangalore), Gwalior (Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur), Hissar (Haryana Agricultural University, Hissar), and in Jammu and Kashmir. The Bhavanisagar center is primarily for research on sorghum and millets; Dharwar center for research on downy mildew and other diseases of sorghum; Gwalior for long-duration pigeonpea, and Hissar for pearl millet, chickpea, and short-duration pigeonpea. These centers are to be established with the cooperation and support of local agricultural universities. For off-season limited work on chickpea, a subcenter in the Kashmir Valley is considered desirable in principle. Preliminary trials on summer crops of chickpea have been started for the purpose.

Excellent cooperative work on *Striga* of sorghum has been started at Punjab Rao Krishi Vidyapeeth, Akola, and in postgraduate training at Andhra Pradesh Agricultural University, Rajendranagar.

Cooperative programs in farming systems research, involving ICRISAT, the Dryland Programs, and selected agricultural universities are getting under way. Locations of the work and cooperating universities are: Sholapur and Mahatma Phule Agricultural University, Rahuri; Bangalore, Bijapur (University of Agricultural Sciences, Bangalore); Indore (Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur) and Ranchi (Rajendra Agricultural University, Bihar); and Himayat Nagar, (coordinated cell of ICAR Dryland Agricultural Program). The projects include study of resource utilization under present management practices, watershed-based resource development and agricultural production in village areas, hydrologic studies to improve water utilization in rainfed agriculture of the Indian SAT, and studies on water utilization in tank-irrigated areas.

In village level studies, conducted in six villages of Sholapur, Akola, and Mahbubnagar districts, the cooperation of the agricultural universities in Maharashtra and Andhra Pradesh in certain phases of the work is mutually beneficial.

Testing of the promising material of sorghum, pearl millet, pigeonpea, and chickpea is being done through the All-India Coordinated Projects for these crops. ICRISAT has developed good facilities for screening pearl millet for downy mildew disease, and promising lines from the Indian program are being screened, thus providing valuable support to the national program. Likewise, sorghum from the Indian program is also being screened for shoot fly-resistance under ICRISAT's program. Similar cooperation is being extended for screening for other important diseases in pulses.

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

Educational opportunities and experiences were provided at ICRISAT Center for scientists, research workers, scholars, and agricultural administrators. All were employed or preparing for employment in rainfed semi-arid agricultural regions of the tropics. Practical field and laboratory experiences were provided to develop skills for more effective participation in research, production, extension, training, or administrative activities in their national or local programs.

Research fellows holding advanced degrees came from India, Sri Lanka, Brazil, and Korea for practical and theoretical experience in their fields of expertise. They worked with ICRISAT scientists on current field and laboratory research projects.

Research scholars from the Sudan and universities in India, Canada, Kenya, the Netherlands, and the United States initiated or continued their thesis research projects as they worked towards their M.Sc. or Ph.D. degrees.

In-service trainees from 19 countries participated in programs of 2 weeks to 6 months in length. The programs, tailored as nearly as possible to meet the individual needs of each student, include practical experience in field and laboratory research, production and resource-management, and crop improvement. French-speaking trainees (Chad, Mali, Mauritania, Niger, Senegal, and Upper Volta) complete a 2-month intensive course in the English language at the Central Institute of English and Foreign Languages on the Osmania University campus in Hyderabad prior to entering their respective training programs.

Table 79. Persons completing long-term training programs during the 1976-1977 report year.

Name	Country	Program
In-service:		
Anne Sara	Senegal	Pearl millet
Diallo Mamadou	Senegal	Pearl millet
Ouattara Sou	Upper Volta	Pearl millet
Lassana Tigana	Mali	Pearl millet
Kern Tolna	Chad	Pearl millet
Hamissan Mijiaba	Niger	Pearl millet
Thiombiano Nadia Luis	Upper Volta	Sorghum
Adama Coulibaly	Mali	Sorghum
Abbo Nassengar	Chad	Sorghum
Sani Idi	Niger	Sorghum
Ankaurao Souleymane	Niger	Sorghum
Abdoa Iro	Niger	Sorghum
Sani Mamman	Nigeria	Crop Production
A.M. Fagge	Nigeria	Crop Production
A.A. Adeniji	Nigeria	Crop Production
A.A. Okolo	Nigeria	Crop Production
Ibrahim I. Kurba	Nigeria	Crop Production
Samuel D.S. Kwabe	Nigeria	Crop Production
S.K. Thakre	India	*Striga*
S.T. Khade	India	*Striga*
Adama Moussa	Niger	*Striga*
Taye Wolde Mariam	Ethiopia	Chickpea
Getahun Terefe	Ethiopia	Chickpea
Abdalla Fageer Ahmed	Sudan	Chickpea
Y.C. Panchal	India	*Striga*
Nagaraj	India	*Striga*
Subbaiah	India	*Striga*
Research Fellows:		
Assanee Pachiburavan	Thailand	Cereal Pathology
U.P. des S. Waidyanatha	Sri Lanka	Microbiology
U.D. Han	Korea	Farming Systems
J.S. Jung	Korea	Farming Systems
Research Scholars:		
B.K. Hadi	India	APAU/IMC
Chandrashekhar Reddy	India	APAU/IMC
Anjali Yadav	USA	Economics
O.I.J. Ogombe Otieno	Kenya	Physiology
Junior Principal Scientists:		
Peter Lawrence	Australia	Sorghum Improvement
Jasper Skinner	USA	Sorghum Improvement
S.O. Okiror	Uganda	Pearl millet Improvement

Table 80. Participants in the ICRISAT training programs, by country.

	1974-75	1975-76	1976-77
Research Fellows:			
India	-	-	1
Korea	-	-	2
Brazil	-	-	1
Sri Lanka	-	-	1
Thailand	-	-	1
Upper Volta	-	1	-
Research Scholars:			
Sudan	-	1	1
India	-	-	5
United States	-	-	2
Canada	-	-	1
Netherlands	-	-	1
Kenya	-	-	1
In-service Trainees:			
Nigeria	4	8	6
India	3	11	71
Sweden	-	1	-
West Germany	-	2	-
Bangladesh	-	1	-
Upper Volta	-	-	2
Senegal	-	-	2
Mali	-	-	2
Chad	-	-	2
Niger	-	-	6
Thailand	-	-	1
Ethiopia	-	-	2
Sudan	-	-	1
Apprentices (university students):			
India	1	3	11
USA	-	-	1

Student agricultural engineers and agricultural economics students from India and United States completed 1- or 2-month apprenticeships working with engineers and scientists in land development; land and water management; farm machinery research, operation, and maintenance; or data processing and analysis.

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. The 1976—1977 report year saw an international workshop and several smaller conferences and workshops. ICRISAT also cooperated with research agencies in India and elsewhere in organizing conferences and workshops, and ICRISAT scientists participated in practically every major scientific meeting involving one or more of its five crops grown in the SAT environment.

International Sorghum Workshop

Fifty-two sorghum specialists from 26 nations participated in the 1977 International Sorghum Workshop at Hyderabad 6-12 March. The purpose of the Workshop was to exchange information about sorghum research in the SAT, determine how best to develop cooperative research among sorghum-improvement workers, review the arrangements for exchanging seed material and information, and to assess training needs and the mechanism for identification of trainees.

One of the highlights of the Workshop was the presentation of country papers. These, along with information gleaned from questionnaires submitted by workers from the 26 nations, provided the most up-to-date appraisal of the SAT sorghum situation available anywhere. Such data is essential for international planning.

Face-to-face interchange of ideas and suggestions was perhaps the most valuable feature of the Workshop. Information flow (from national program to ICRISAT, from ICRISAT to national program, and between national programs) is essential if the sorghum workers of the world are to provide the most effective assistance to the small SAT farmer of limited means.

The All-India Coordinated Sorghum Improvement Project served as co-sponsor for the Workshop.

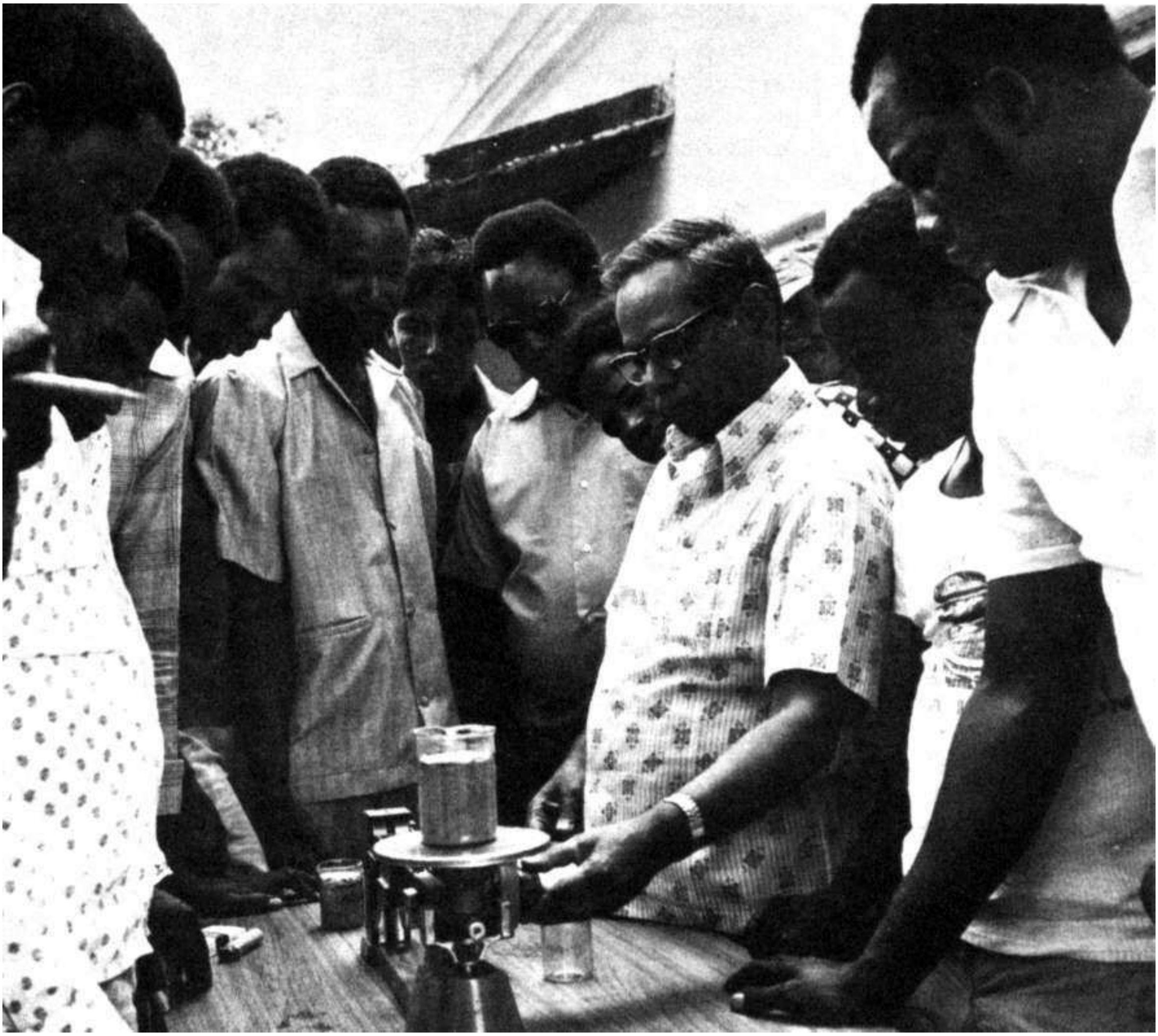


Figure 99. ICRISAT's program for inservice trainees emphasizes practical agriculture along with scientific principles. Fertilizer solutions is the topic here.

DPAP Training Conference

A 6-day training conference was held in April for 35 agricultural officers from five Drought Prone Area Program districts in three Indian states. The purpose was to acquaint the officers with the latest developments in crop production technology and resource management, and to establish communication exchange with development workers and researchers. The program was jointly organized by the All-India Coordinated Research Project for Dryland Agriculture, the Central Soil and Water Conservation Research and Training Institute, agricultural universities in the three states, DPAP, and ICRISAT.

Chickpea Breeders' Meeting

The annual chickpea breeders' meeting was held on 24-25 February at ICRISAT Center. Thirty breeders from India and a breeder from Israel met to review the progress of breeding, pathology, germplasm, entomology, microbiology, physiology, and nutritional quality and to tour ICRISAT Center. Interspecific hybridization in chickpea occupied one half-day session, and the final afternoon of the meet was spent in the field, where the visiting breeders selected lines thought to be useful in their own programs.

Seminars

Institute and program seminars are a regular feature of life at ICRISAT. Institute seminars are scheduled monthly, and many of the programs schedule weekly seminars. Visiting scientists usually present one or more seminars during their stay at ICRISAT. These activities provide a valuable forum for exchange of ideas and information.

Field Trips and Visits

ICRISAT frequently schedules field trips and other short-time activities for visiting groups. The Institute considers this to be a valuable avenue of information exchange. Occasionally, such activities serve a special purpose. For example, during September, all of the millet breeders in India visited ICRISAT Center to become more familiar with the research program and to make their own selections from ICRISAT's breeding nurseries. Discussions with these workers regarding the future direction of ICRISAT's efforts in breeding and pathology were quite useful.

Plant Quarantine

For the proper execution of crop improvement programs at ICRISAT and elsewhere in the SAT, the exchange of valuable seed material with our scientists in the outreach programs and other colleagues in cooperative programs throughout the world was carried out through the Plant Quarantine Services of Government of India. Sorghum, pearl millet, pigeonpea, chickpea, and groundnut were inspected and cleared at the Central Plant Protection Training Institute, located in Hyderabad. Seed material of other crops essential in the Farming Systems research program was cleared at the National Bureau of Plant Genetic Resources in New Delhi. Unrooted groundnut cuttings were released by the Directorate *of* Plant Protection, Quarantine, and Storage, Faridabad.

Export of Seed Material

During the year, 38 886 samples of sorghum, pearl millet, chickpea, pigeonpea, and groundnut were exported to 72 countries of the world (Table 81).

A total of 20 676 sorghum samples were sent to 38 countries. International cooperative trials consisting of population progeny lines, grain mold resistant, pests and disease resistance, *Striga* resistant, and grain grass cultivars numbering 12632 were sent to our scientists and cooperators/collaborators in Botswana, Cameroun, Ethiopia, Ghana, Kenya, Malawi, Mali, Mexico, Niger, Nigeria, Pakistan, Saudi Arabia, Senegal, Somalia, Sudan, Tanzania, Thailand, and Upper Volta. Segregating material and cultivars totalling 6316 were sent to 33 countries, the bulk of it going to Bangladesh, Botswana, Brazil, Cameroun, Ecuador, El Salvador, Kenya, Malawi, Malaysia, Nicaragua, Nigeria, Tanzania, Yemen, and Zambia. Germplasm cultivars totalling 1 728 were exported to Bangladesh, Ethiopia, Malawi, Malaysia, Mexico, Somalia, Venezuela, and West Germany. Saudi Arabia and Venezuela received 36 drought-resistant, salt- and heat-tolerant lines.

Of the 8081 pearl millet samples sent to 29 countries, 4702 went out as International cooperative trials to 19 countries. Downy Mildew, Ergot, and Smut Nurseries were sent to Nigeria, Senegal, and Upper Volta; 2731 cultivars consisting of germplasm, varieties, composites, synthetics, and segregating materials were sent to Ethiopia, Libya, Mexico, Niger, People's Republic of China, Senegal, Venezuela, West Germany, and Zaire. Forty-eight samples were sent to Canada, England, and Denmark for carrying out biochemical studies.

International Chickpea Cooperative Trials material formed the bulk of chickpea export. Of the total of 7 218 trial samples, 6 661 were sent to cooperators/collaborators in 27 SAT countries. Germplasm and segregating cultivars numbering S6S were sent to Botswana, Canada, Italy, France, Kenya, New Zealand, Syria, USA, Venezuela, and Zambia. Thirty-four samples were sent to various agencies in England and USA for physiological and biochemical studies.

Pigeonpea samples were sent to 34 countries. Seed samples totalling 494 went as vegetable-type observation nurseries to Belize, El Salvador, Dominican Republic, Panama, Philippines, Puerto Rico, Venezuela, and Zambia. Germplasm cultivars numbering 1277 were exported to Australia, Ghana, Malaysia, Mauritania, Puerto Rico, and Tanzania. Varietal trial entries and varietal purification cultivars numbering 966 were sent to 22 countries. Twenty-eight samples went to Canada and Denmark for biochemical studies.

A total of 146 groundnut cultivars were exported to Australia, Malaysia, Pakistan, Sri Lanka, and West Indies. One-hundred samples went as germplasm cultivars; 46 observational trial entries were exported to Sri Lanka.

Twenty samples of safflower, paddy, wheat, cowpea, and dried neem leaves were examined and cleared at the National Bureau of Plant Genetic Resources, New Delhi, for despatch to Nigeria, Taiwan, Thailand, and Upper Volta.

Table 81. Seed samples exported or imported by ICRISAT daring 1976-1977.

	Sorghum		Millet		Chickpea		Pigeonpea		Groundnut		Other	
Country	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp
Botswana	929				22							
Cameroun	388											
Cape Verde Islands	52											
Central African Republic	52											
Egypt					490							
Ethiopia	4313	413	69		414							
Ghana	325						51					
Kenya	1335				10		25					1
Libya			14		250							
Malawi	389		65				4					
Mali	309		120									
Mauritania							51					
Niger	735		277									
Nigeria	949	2	1966				222	15			1	1
Senegal	615		1378	60	74							1
Sierra Leone							20					
Somalia	892		60									
Sudan	2154		595		195		2					
Tanzania	529		120		150		98					
Tunisia					135							
Uganda			60									100
Upper Volta	1905		1319	64							10	2
Zaire			20				14					
Zambia	33				50		103			1		
Afghanistan					150	20						13
Bangladesh	730	7	60		681			1				
Burma					358		12					
Iran					150							
Iraq					185							
Japan							6			43		
Jordan					135							
Korea							5					
Malaysia	142						25		36			
Nepal					184		12					
New Guinea	14											
Pakistan	791		1406		1073		20		3			
People's Republic of China	35		12									
Philippines					274		38					

continued

Table 81 *continued*

Country	Sorghum Exp	Sorghum Imp	Millet Exp	Millet Imp	Chickpea Exp	Chickpea Imp	Pigeonpea Exp	Pigeonpea Imp	Groundnut Exp	Groundnut Imp	Other Exp	Other Imp
Saudi Arabia	92		4		25							
Sri Lanka	52				49		19		46			
Syria			60		588							
Taiwan	25										1	
Thailand	1708	2	60		249		33				8	
USSR		6										
Yemen Arab Republic	238		60		74		11					
Argentina					25							
Brazil	100	11	120				8					
Chile			60		189							
Colombia	10		60				10					
Dominican Rep.							424					
Ecuador	107											
El Salvador	51						63					
Mexico	442		46		414							8
Netherlands						3	15					
Nicaragua	50											
Panama							38					
Peru					164							
Puerto Rico							184	17		14		
Venezuela	44		18		20		104					
West Indies	26						67		25			
Belize							38					
Denmark			15		7		24					
England			21		30					202		82
France					12			7				
Italy					10							
Spain					35		15					
Turkey					280							
West Germany	2		4									
Australia	34					25	1000		36			47
Canada			12		9		4					
New Zealand					40							
USA	79	275			18					338		4
	20676	716	8081	124	7218	48	2765	40	146	598	20	259
Total	21392		8205		7266		2805		744		279	

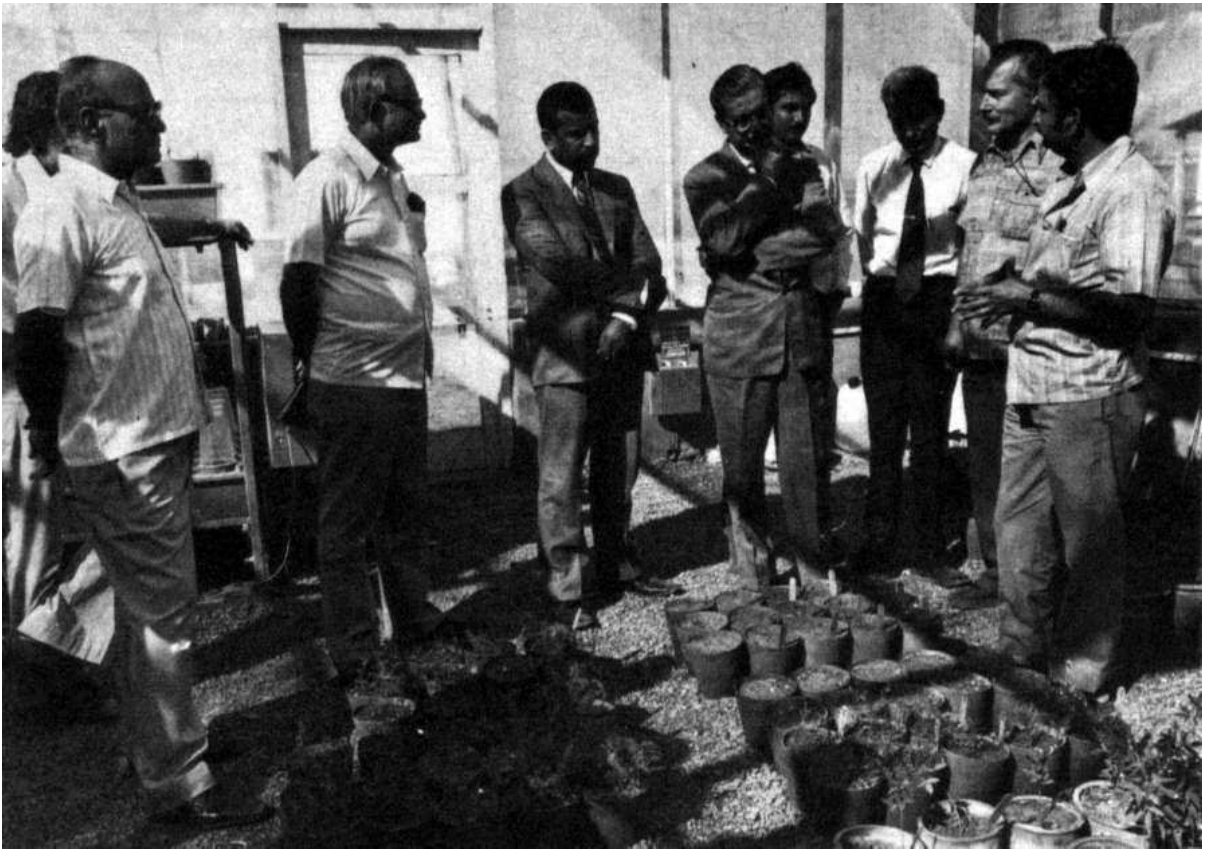


Figure 100. ICRISA T plant quarantine scientists and quarantine officials of the Government of India work together to assure minimum delay in import and export of seed materials.

Import of Seed Material

ICRISAT received 1 785 samples of sorghum, pearl millet, chickpea, pigeonpea, and groundnut along with seed material of some other crops for use in our Farming Systems research program from Afghanistan, Australia, Bangladesh, Brazil, Colombia, England, Ethiopia, France, Japan, Kenya, Mexico, Philippines, Netherlands, Nigeria, Puerto Rico, Senegal, Thailand, Upper Volta, USSR, USA, and Zambia (Table 81).

Bulk of the sorghum introductions came from Ethiopia (413) and the USA (275) - Washington 12, Texas 16, Minnesota 17, Mississippi 18, Illinois 22 *{Shoot-fly resistant sorghum* x *sugarcane* crosses), Nebraska 81, and Purdue 109. These materials were imported to utilize their yield, physiological, microbiological, disease- and pest-resistance attributes and to fill gaps in our germplasm collections. A total of 124 lines of pearl millet germplasm and disease resistance material were introduced from Senegal and Upper Volta.

Forty-eight chickpea cultivars were introduced from Afghanistan, Australia, and Netherlands under the germplasm exchange program. Agricultural research agencies of France, Nigeria, and Puerto Rico formed the main sources of pigeonpea germplasm and breeding lines to ICRISAT.

For groundnut improvement, 192 unrooted cuttings of interspecific hybrids of *Arachis* spp. were received from Dr. Phil Moss's collection at the University of Reading, UK, for testing their reactions to *Cercospora* leafspot. In addition, 406 cultivars -comprising germplasm lines, disease resistant material, released cultivars, and genetic marker lines -were received from North Carolina and Georgia in the USA, Japan, Puerto Rico, and Zambia.

In other crops, 259 samples of *Acacia,* beans, Bermuda grass, corn, cowpea, *Cicer herbarium,* jojoba, *Leucaena latisiliqua, Phaseolus atropurpureus, Setaria,* and *Sesamum* were cleared at the National Bureau of Plant Genetic Resources, New Delhi for the Farming Systems and Crop Improvement programs.

Quarantine Regulations for Release of Pearl Millet and Groundnut Imports

Pearl Millet: The ICAR Quarantine Committee on pearl millet seed imports recommended on 21 Dec 1976, certain procedures that, if followed, would permit pearl millet seed to be introduced without the risk of the introduction of pearl millet downy mildew. The procedures were: (i) seed should be collected from downy mildew-free plants; (ii) seed should be physiologically mature, dry, and treated with fungicides before despatch; and (iii) on arrival the seed should be soaked in a 1:1000 solution of $HgCl_2$ for 10 minutes, then immediately washed in four washes of sterile water. After washing, the seed be transferred immediately into a water bath set at 55°C for 12 minutes. Following the water bath, the seed should be placed in an incubator set at 35°C for 12 hours and then at 40°C for an additional 12 hours. This procedure was followed by the quarantine officers at Central Plant Protection Training Institute and 124 samples of pearl millet seed imported from West Africa were released to us for planting in the Post-Entry Quarantine Isolation Area at ICRISAT Center.

However, in view of a letter received from Dr. Neergaard, Director General of the Danish Institute of Seed Pathology for Developing Countries in Copenhagen, in Feb 1977, on his Institute's inability to guarantee the hot-water treatment of pearl millet seed for purposes of quarantine clearance, Dr. M.S. Swaminathan, Director General, Indian Council of Agricultural Research, organized a meeting of ICRISAT and Indian government scientists in April 1977 to review the quarantine arrangements for ICRISAT seed. In this meeting it was decided that a committee should reconsider the methodology of treating future pearl millet seed consignments for quarantine clearance.

The appointed committee met and concluded that treatment of seeds with CIBA fungicide CGA-1-82/50W at a rate of 3 g/kg seed in 1000 ml water for 6 hours, in addition to the procedures recommended in the December 1976 meeting, should afford adequate safeguard against the risk of the pathogen being introduced through pearl millet seed imported by ICRISAT.

Groundnut: The earlier procedure of growing imported seed material in the Post-Entry Quarantine Isolation Area and releasing the seed of the healthy plants was discontinued. After prolonged discussion with the Directorate of Plant Protection, Quarantine, and Storage, Government of India at New Delhi, the procedure for releasing groundnut seeds was finalized. Ten seeds from each sample would be grown in the nethouse at Central Plant Protection Training Institute and kept under strict observations for a period of 6 to 8 weeks. Seedlings showing the slightest symptoms of an exotic disease were discarded; healthy seedlings were released for planting in the Post-Entry Quarantine Isolation Area at the ICRISAT Center. The material was again inspected until harvest by Government of India and ICRISAT scientists. This procedure, though slow, is working out satisfactorily, and 406 cultivars have been cleared during the year.

Postentry Quarantine

It was decided in ICAR Quarantine Committee meetings in December 1976 and reconfirmed in the meeting of April 1977 that all the imported seed material released after quarantine inspection would be grown for the first generation in the Post-Entry Quarantine Isolation Area at ICRISAT Center. The crops would be inspected by Government of India quarantine officers and ICRISAT scientists at weekly intervals until harvest, and any plant showing symptoms of exotic disease would be destroyed.

Consequently, 124 cultivars of pearl millet imported from West Africa were grown in the Post-Entry Quarantine Isolation Area and examined periodically. Some plants showing doubtful disease symptoms were destroyed, but all cultivars are still growing, and it is hoped that we will be able to harvest seed material from all released cultivars for our experimental work.

Six-week-old seedlings of 406 cultivars of groundnut released after careful inspection for 6 to 8 weeks in Central Plant Protection Training Institute nethouse were planted in the Post-Entry Quarantine Isolation Area during the year. Similarly 192 unrooted cuttings of *Arachis* spp., after growing for 6 to 8 weeks in our nethouse, were also transplanted to this area. These plants were examined each fortnight and all doubtful plants were removed and destroyed. However, not one of the released entries was totally lost due to disease incidence.

Facilities Provided by ICRISAT

To assist in the speedy clearance of its seed material, ICRISAT has provided an inspection room and fumigation chamber at Central Plant Protection Training Institute. This facility was formally presented to CPPTI by Director L.D. Swindale in April 1977.

Computer Services

ICRISAT's Computer Services unit is equipped with a "DECdata" system 550, which it operates as a dedicated timesharing system utilizing the RSTS/E (Resource Sharing Time Sharing Extended) operating procedure. Resources of the system are accessible to ICRISAT scientists through terminals located in the computer center.

Objectives

The goal of the Computer Services unit is to integrate the use of the ICRISAT computer system into the daily routine of the research, administrative, and service activities of the Institute. In order to achieve this goal, the Computer Services unit is

(i) developing interactive systems which are easy to use,

(ii) providing data-entry services, and

(iii) conducting seminars on computer usage and programming.

Current Stage of Development

The major emphasis in Computer Services during the past year has been on the improvement of the statistical-analysis capability of the system. The file structure used to store research data in on-line disk files was improved to permit the storing of larger collections of data more efficiently. Eleven new data-editing options were introduced and the entire set of editing routines was grouped into a file-editing subsystem. This subsystem permits the different editing options to be invoked through the specification of a two-letter code. The statistical-analysis routines were integrated into a single system called the Crop Research Integrated Statistical Package (CRISP), which permits the use of a set of commands for selecting the desired analysis. A single computer-system command is required to gain access to CRISP. Under CRISP, the user can proceed through a sequence of analyses by choosing the appropriate options and does not have to revert to computer-system commands. At present there are 42 statistical-analysis and data-manipulation routines available under CRISP. Access to the file-editing subsystem is gained through two CRISP commands.

The system developed to store and maintain Village Level Studies data collected by the Economics Program was improved by the addition of a subsetting capability. This feature permits the selection of a subset of data from a data file, based on a logical combination of conditions imposed on the data. A conversion routine was developed which permits restructuring of the Economics Program file structure into the structure required under CRISP, in order that existing statistical analysis routines can be used to analyze this data also. A modified form of the system developed for the Economics Program is being used to store and maintain ICRISAT's germplasm data. During the next year, an improved system for storage and retrieval of large data bases will be developed to accommodate both the Economics and germplasm data.

An improved system for performing randomizations, printing seed-packet labels, and generating field books was introduced to the users in early May, 1977. Under this system the name and description of, factor identification for, and the person responsible for the experiment are stored in a file on disk. The resultant randomization is also stored in this file. This information is used to initialize the data file required to store the data for analysis, using routines under CRISP. Data can be entered directly from field books without reordering, thus reducing the occurrence of transcription errors. The field book system is accessed through commands under CRISP.

Work has progressed on the computerized fiscal accounting system and various aspects of it have been under test since April. Under this system, all operational, capital, and special accounts will be stored in a disk file. Each day a transaction file is created from input at a terminal and the accounts in the budget file are updated from these transactions. Once the system is fully operational, all accounts will be current to the previous day and the status of any account will be readily accessible.

Dr. Jerry A. Warren, statistical consultant from the University of New Hampshire in the United States, visited ICRISAT again during January and February, 1977. He conducted classes in regression analysis and experimental design, consulted with scientists concerning planning of experiments and required analyses, and instructed staff members how to best utilize the analysis routines under CRISP.

Looking Ahead in Computer Services

Projects scheduled to receive attention in the coming year include:

1. Completion of the fiscal accounting system and the addition of a payroll system.

2. Development of on-line systems for inventory control and purchase-order statistics.

3. A compact system for the maintenance of Institute mailing lists.

4. Improvement *of* the germplasm-retrieval system and development of inventory-control systems for the management of available seed.

5. A personnel data base for the Personnel Division.

6. Investigation of word-processing and computer-generated offset masters for printing.

Library

The Library was shifted from its crowded quarters in the Banjara Hills district of Hyderabad to ICRISAT Center on 28 February 1977. The new quarters, although temporary, are spacious and accommodative for the time being. Permanent Library facilities are expected to be ready sometime near the end of 1978.

Acquisition

The Library continues to acquire only highly specialized research documents pertaining to the areas of interest to ICRISAT scientists. The procurement of each document, therefore, requires special efforts. Growth in the Library collection is presented in Table 82.

Catalog

The card catalog of back-volumes of periodical holdings has been maintained in addition to the usual Official Catalog, Public Catalog, Shelf List, and Accession List. Back volumes and the subscribed completed volumes of periodicals have been bound. In all 1 133 books and periodicals were bound during the period of report, making a total of 4000 bound volumes of periodicals available to Library users.

During the period under report 109 documents were supplied to libraries and scientists in ICRISATs areas of interest over the world. These figures reveal the excellent relations that the ICRISAT Library is maintaining with other libraries.

The ICRISAT Library has up-dated its collection of the annual reports of various international and other institutions with areas of research similar to ICRISAT. It now has a unique collection of annual reports from 130 institutions of 28 countries. This helps our scientists to avoid research-in-parallel and in planning their research-in-series.

Another unique collection consists of copies of all the papers and tour reports of ICRISAT scientists.

Documentation

In the field of documentation, the Library has published the following:

ICRISAT Library: Monthly List of Additions.

Catalog of Periodicals: ICRISAT Library. 1976.

Bibliography of Theses on ICRISAT Specialities. 1977.

Cooperation in Agricultural Libraries in India. Paper presented at ICAR-PAU Seminar

Table 82. Accessions of the ICRISAT Library.

	Total Mar 1974	Total Mar 1975	Total May 1976	Added 1976-1977	Total May 1977
Books	580	2688	5225	2385	7610
Bound volumes of periodicals	231	1045	2551	1469	4020
Microforms	-	311	471	389	860
Periodicals subscribed	232	344	394	193	587
	23				
Reprints for master file of bibliographies	-	-	-	1400	1400
Total (less periodicals)					13890

on Agricultural Librarianship and Documentation, Ludhiana, 2-5 Feb 1977.

Role of Information Science in Agricultural Research; Sorghums and Millets Information Center. Paper presented in International Sorghum Workshop, Hyderabad, 6-12 Mar 1977.

Sorghums and Millets Information Center

The Sorghums and Millets Information Center (SMIC) originated from an idea presented at the Workshop for the Development of an International Sorghum and Millet Information Network held 12-13 May 1975 in the United States. With funding assistance from the International Development Research Centre (IDRC), SMIC was established in December 1976.

The concept of an information/documentation center recognizes that research workers do not have ample time to scan the ever-increasing numbers of periodicals, even those in their particular areas of interests. Unlike the traditional library, an information/documentation center reviews the contents of periodic literature, culls out relevant literature, publishes *that* information in the form of bibliographies, and collects master files from which copies can be prepared for ready dissemination.

Specific Objectives

SMIC's specific objectives are:

(a) to collect documents on sorghums and millets dating from 1969 onwards;

(b) to set up an appropriate document storage and retrieval system;

(c) to bring up to date the existing bibliographies on sorghums and millets;

(d) to provide bibliographic search services for scientists in developing countries;

(e) to provide upon request, particularly for developing countries, copies of material in the document collection;

(F) to establish a question-and-answer service, using the advice of the scientists in ICRISAT's research network; and

(g) to issue a newsletter to reinforce the research network and to improve communications with outside institutions.

Work Accomplished

Master copies of references cited in the existing standard bibliographies of millets are being procured. So far, about one-fourth of the appropriate documents have been secured. They have been obtained from the collection in ICRISAT Library and through the collection search of local specialized libraries. Cooperation extended by local libraries has been most helpful.

Efforts are being made to collect master files of all the references pertinent to sorghum and millet, so that any scientist may get a copy of the material at any time. The master copies so far collected have been filed according to the entry numbers of the main bibliography.

Work in Progress

Lists of reference publications, abstracting, reviewing, and other periodicals in English, French, and Spanish are being prepared for purchase on priority basis.

Future Plans

The Sorghums and Millets Information Center would be responsible for the collection, documentation, and retrieval of all information on sorghums and millets. The work will be undertaken primarily in English and French languages; other languages may be included as per requirement and importance. The ICRISAT Library has already a good collection of sorghums and millets bibliographies in its possession.

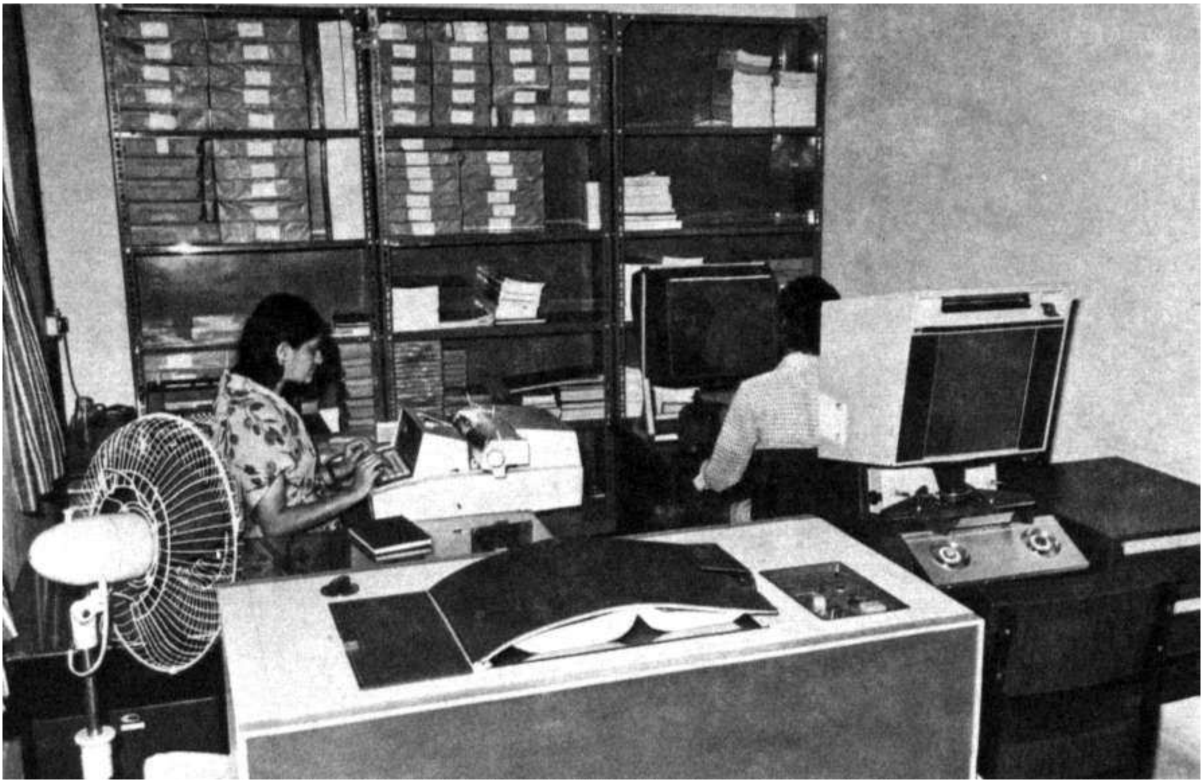


Figure 101. The ICRISAT Library and the Sorghums and Millets Information Center are tooling up to serve the information needs of the scientists working with sorghum, pearl millet, pigeonpea, chickpea, and groundnut throughout the SAT.

After documentation and collection work is over, SMIC intends to finalize its retrieval system and produce at regular intervals supplements to the existing bibliographies on both crops. It hopes to develop the capability of performing specific subject searches on demand, and to maintain profiles of sorghum scientists' specific subject areas of research.

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