BIBLIOGRAPHIC DATA SHEET

1. CONTROL NUMBER	PN-AAH-645
2. SUBJECT CLASSIFICATION (695)	AA50-0000GG50

3. TITLE AND SUBTITLE (240)

Annual report, 1973/1974

4. PERSONAL AUTHORS (100)

5. CORPORATE AUTHORS (101)

Int. Crops Research Institute for the Semi-Arid Tropics

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1974	93p.	633.1.I61d-1973/1974

9. REFERENCE ORGANIZATION (130)

ICRISAT

10. SUPPLEMENTARY NOTES (500)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Agricultural research
Sorghum
Chick peas
Tropics
Farming systems
Farm management
Agricultural economics
Pearl millet
Pigeon peas
Semiarid land
Agricultural production

13. PROJECT NUMBER (150)

931097 200

14. CONTRACT NO. (140)

AID/ta-G-1499

15. CONTRACT TYPE (140)

16. TYPE OF DOCUMENT (160)

52

AID 590-7 (10-79)

ICRISAT

ANNUAL REPORT 1973-74

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

PN-AAH-645

ICRISAT Annual Report

1973 1974

International Crops Research Institute for the Semi-Arid Tropics
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ABOUT THIS REPORT

This is the first annual report of the International Crops Research Institute for the Semi-Arid Tropics which has been printed for worldwide distribution. The report gives research highlights for the period from 1 April 1973 to 31 March 1974. A report for our first year of operation (1972–73) covered preliminary investigations of Farming Systems, the single program which began activities that year.

Detailed reporting of the extensive activities of ICRISAT's many research support units is beyond the scope of this report, but the Director's Introduction lists some of the important contributions of these units to ICRISAT's research program.

Data in this publication are reported exclusively in the metric system. The unit "t/ha" refers to metric tons (1,000-kg) per hectare and "q/ha" denotes quintals (100-kg) per hectare.

The Hindi word *kharif* is used to refer to the monsoon season, generally occurring from June through September or early October. The Hindi word *rabi* is used for the dry, post-monsoon season, generally occurring from October through January.

ICRISAT receives support from ten members of the Consultative Group on International Agricultural Research. The responsibility for all aspects of this publication rests with the International Crops Research Institute for the Semi-Arid Tropics. Mention of particular insecticides, fungicides, herbicides or other chemicals or mention of individual varieties does not necessarily imply endorsement by the Institute.

The correct citation for this report is International Crops Research Institute for the Semi-Arid Tropics, 1974. *ICRISAT Annual Report 1973–74*. Hyderabad, India.

Director's Introduction

ICRISAT has four main objectives:

1. To serve as a world center to improve the genetic potential for grain yield and nutritional quality of sorghum, pearl millet, pigeonpea and chickpea. Groundnuts will be added as a fifth crop next year.
2. 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.
3. 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.
4. To assist national and regional research programs through cooperation and support and contributing further by sponsoring conferences, operating international training programs and assisting extension activities.

This report offers a benchmark of the Institute's progress in tackling the myriad problems associated with those objectives. ICRISAT began formally on 5 July 1972 with the adoption of its constitution and the establishment of its Governing Board. An informal beginning came about six weeks earlier. A small group of professionals—some on loan from other agencies—prepared sites and managed to have experimental crops in the ground for the 1972 monsoon season.

As the year 1973–74 came on, the tempo quickened. At the beginning of the "ICRISAT year" in April 1973, five international staff members were launching research programs with the able assistance of seven research associates and assistants. They worked in hastily-constructed, temporary buildings on the experiment station and rented quarters in Hyderabad.

By March, the end of our reporting year, 13 international staff members and 27 associates and assistants were on board. Additional office and laboratory space had been rented in the city and close to the experiment station. But the emphasis has been on research. The highlights:

Cereals

- We obtained 12,693 lines of sorghum and 6,612 of millet, making a good start on gathering the available germplasm from all over the world.
- We began breeding work on populations and preliminary work on pathology and entomology.
- We demonstrated that two full generations of sorghums and millets can be grown at ICRISAT and shorter duration lines of both can be grown in the short summer season. With the possibility of producing three generations of some lines, we will have minimum time-lapse from original crosses to the segregated, selected and fully-evaluated genetic materials we seek.

Pulses

- We obtained 5,958 lines of chickpea and 3,439 lines of pigeonpea in the first systematic international effort to gather, evaluate, and utilize the world's full genetic wealth of these important sources of protein.
- With limited staff and resources, we made an unusually large number of crosses in these self-pollinated crops.
- We established an off-season nursery of chickpeas in Lebanon and launched investigations into photoperiod sensitivity of pigeonpea in an effort to find means to reduce the time requirements between crosses and evaluated material.

Farming Systems

- We began our second year of studies on fertilizer response, intercropping, pearl millet ratooning, performance of various crops and other production factors in the semi-arid tropics. Relay cropping, method of planting, and root sampling studies launched this year have contributed to our knowledge of rainfed farming systems.
- Investigations on resource management were initiated on five experimental watersheds in the black soils. The data gathered through extensive preliminary observations has enabled us to plan more precise experiments on both red and black soil watersheds in subsequent seasons.

These and other research results speak for themselves. Perhaps less obvious are the behind-the-scenes efforts of the many individuals and organizations that have made this success possible. A sampling of some would include:

PREDECESSORS AND CONTEMPORARIES

ICRISAT does not claim a bootstrap beginning. Review of the work of many talented researchers from its host country and elsewhere has contributed substantially to our program. We have received direct assistance from many helpers.

The Government of India provided 1,394-hectares of land for the Institute in cooperation with the Government of Andhra Pradesh. Host country officials at all levels of government have extended valuable collaboration.

We have gained knowledge through the experience and cooperation of the other international agricultural research institutes. They are:

International Maize and Wheat Improvement Center (CIMMYT), Mexico City, Mexico

International Rice Research Institute (IRRI), Los Banos, Philippines

International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria

International Potato Center (CIP), Lima, Peru

International Center of Tropical Agriculture (CIAT), Cali, Colombia

Two additional centers, the International Livestock Center for Africa (ILCA), in Ethiopia and the International Laboratory for Research on Animal Diseases (ILRAD), in Kenya are under development.

Assembly of germplasm is a result of the generous cooperation of the world's leading breeders of the four crops. The All-India Coordinated Sorghum Improvement Project at nearby Rajendranagar has one of the best sorghum collections in the world. It was freely opened to ICRISAT's cereal breeders.

Similar contributions in all four crops were made by many individuals and programs from all corners of the globe. Some of these collaborators are mentioned in appropriate sections of this report. But help and cooperation came from so many sources it is impossible to give proper credit individually.

This is equally true of the soil scientists, engineers, agronomists and other professionals who helped shape concepts basic to the farming systems program. The All-India Coordinated Project on Dryland Agriculture with headquarters at Rajendranagar is one outstanding example, but again, our debts are too numerous to elaborate one by one. We hope the results of our work will provide some compensation to these dedicated contributors.

ICRISAT RESEARCH SUPPORT STAFF

Some of our support units have started with one or two individuals and grown with the Institute. Others began as our report year ended, so their activities were largely developmental. All have important backstop missions which directly facilitate our research in the field and overall goals. The brief description here does not do justice to their contribution.

Economics and Statistics. ICRISAT economists and statisticians will be involved in both supportive and independent research. They began research only six weeks before the ICRISAT year ended. In that time, a major policy paper was produced and the senior economist contributed to a feasibility study on the proposal of conducting groundnut research at ICRISAT.

Entomology, Plant Physiology and Plant Pathology. Work in entomology, plant physiology and plant pathology in 1973–74 was carried out by international staff from allied disciplines and research associates. As the year ended, international scientists joined to head the entomology and physiology efforts in the major programs; we hope to have a senior plant pathologist soon.

Administration. Assistants to the director and associate director; records and personnel staff; officers and assistants in our Delhi office, fiscal division, purchase and supplies unit; and the secretarial and general service people attached to the various program units have set a high standard of efficiency in this fast-growth and development stage. Their efforts have permitted research to get underway immediately.

Physical Plant Services. The staff and mission of ICRISAT cannot wait for construction of the eventual physical plant at the experiment station. Temporary buildings had to be constructed and rented quarters renovated and equipped. At the same time, detailed and careful plans had to be made for permanent facilities. Physical Plant Services have tackled both these tasks.

Three buildings in Hyderabad were rented and fitted to the immediate needs of ICRISAT. One required extensive alteration and fitting to house our laboratories. Additional buildings at the experiment station, either constructed or rented and renovated, provide field laboratories, machine shops, and offices.

The Institute's architects, Doshi and Stein of Ahmedabad and New Delhi moved planning and designs for the Institute's permanent buildings to the stage of tender documents. Construction will utilize materials and techniques indigenous to South India. Our target date for occupancy at the experiment station is late 1976.

Farm Development and Operations. We have put land into production at ICRISAT as rapidly as equipment and manpower allowed. First priority in the development of our 1,394-hectare experiment station has been layout and leveling of 140-ha. of precision farming area for Crop Improvement and preparation of research watersheds and fields for Farming Systems. Mr. W.D. Ware-Austin, Overseas Development Agency of the United Kingdom, produced a detailed program of development for the ICRISAT experiment station. With modifications by other competent planners, this provides our guide.

Construction of roads; building tanks and irrigation systems; and repair and fabrication of machinery are some of the other activities of this dynamic unit.

Then, there are the regular field operations—with suitable modification to meet the complicated demands for research. When these operations began in 1973–74, only six field tractors were in operation. Ahead of the crew were three crop seasons of sorghum and pearl millet, one crop of chickpea and pigeonpea, plus relay and multiple cropping programs on experimental watersheds and a variety of production research trials. With the acquisition of a few additional tractors, more than 5,200 operational hours were required to complete the task, plus considerable field work by bullock for traditional practices studies.

Irrigation was required for second and third generations of the cereal crops Almost 11-ha/m of water were delivered from borewells and ponds to over 200-ha. of crops.

Biochemistry Laboratory. The biochemistry laboratory was equipped and staffed under the leadership of Dr. R. Jambunathan, on three-month loan from the Purdue University Sorghum Project. Protein analysis of hundreds of lines of sorghum, pearl millet, chickpea and pigeonpea by UDY, Neotec and Beckman Amino Acid Analyzer is now being conducted to guide plant breeders' selections. Seed boldness, nutrient content and other grain qualities can be measured in the laboratory.

Library. A professional agricultural librarian joined the Institute in December 1973. An acquisition program began immediately and by March 31, we had 530 books, 231 bound volumes of periodicals and the start of subscriptions for 192 periodicals. Exchange relations have been established with 100 institutions in India and abroad.

Acquisitions focus on research materials on the ICRISAT crops and farming systems for the semi-arid tropics. Our permanent library building will have capacity for 73,000 books and periodicals; 1,000 current periodicals; 45 readers; 20 cubicles; a reprographic laboratory; microfilm reading and storage; and bindery.

Information Services. Information Services started official operations in February 1974. Prior groundwork had been done by Communications Consultant William B. Ward, Cornell University, who produced two explanatory brochures that were circulated internationally. Dr. K.R. Kern, Iowa State University, arrived in February on a six-month assignment to head the unit.

We initiated the quarterly newsletter, *AT·ICRISAT*, and have started compilation of an international mailing list.

OUTREACH

Outreach is fundamental to the ICRISAT mission. We have concentrated initial efforts in three main areas: cooperating centers, training, and hosting national and international visitors.

Cooperating Centers. We took significant early steps this year to establish a network of cooperating centers throughout the semi-arid regions of Africa, South America, and Asia. These centers will play a vital role in testing and adapting genetic materials and farming systems principles in diverse agro-climatic regions. The centers also offer a crucial link in the agricultural development chain through relationships with national and regional agricultural service systems which are in direct contact with farmers in the semi-arid tropics.

Training. We have planned an early beginning to the ICRISAT training program. We have established a training hostel to house as many as 20 trainees. A pilot production training program will begin in May 1974 with four Nigerian participants.

Hosting National and International Visitors. Another type of outreach occurs on the experiment station at Hyderabad. Contact with international scientists and agriculturists is a mutually beneficial experience. During the twelve months reported here, official visitors totaled 1,084. They came from 37 nations. In addition, we had a large number of informal visitors.

Additional Outreach. We are planning additional outreach such as international conferences and workshops in the near future. We have made a conscious effort to establish communication with a host of related institutions and researchers involved in agricultural development both within India and Asia and on other continents.

GOVERNING BOARD

One meeting of the full governing board, three meetings of the executive committee, and one meeting of the program committee and of the UNDP project development advisory committee helped on-site administrators steer the course of this active, growing year. Two Indian members of the governing board completed periods of service, Mr. T. Swaminathan, former Cabinet Secretary, Government of India, and Mr. V.K. Rao, former Chief Secretary of the Andhra Pradesh Government. They were replaced on the board by respectively Mr. B.D. Pande and Mr. N. Bhagwandas.

A new member of the Governing Board was appointed, Dr. Djibril Sene, Delegat Generale de la Recherche Scientifique et Technique, Senegal. He became the fourteenth member of the international body which now has members from 11 countries.

FINANCE

ICRISAT is supported by the Consultative Group on International Agricultural Research which consists of 29 organizations involving many international bodies, several foundations, and governments representing 17 countries. These donors provided the funds for ICRISAT's 1973–74 operating and capital budget:

Canadian Government
Federal Republic of Germany
International Bank for Reconstruction and Development
International Development Research Center, Canada
Norwegian Government
Swedish Government
Swiss Government
United Nations Development Program
United Kingdom Government
United States Government

CONCLUSION

This report represents the combined, direct or indirect efforts of hundreds—perhaps thousands—of people. However, compared to the problems and potentials we face and the toil—the often fruitless and frustrating toil—of the 500 million people of the semi-arid tropics, it is a small investment. Through the continued support of those who have and are contributing knowledge, interest, capital and goodwill, we hope that investment will pay disproportionately large dividends through an improved quality of life for the people we serve.

WEATHER—APRIL 1973–MARCH 1974

Monthly rainfall at ICRISAT from April 1973 to March 1974 and 30-year averages for the Hyderabad area are given in Table 1 Figure 1 presents the data graphically.

Table 1. Monthly Rainfall in 1973–74 at ICRISAT and Percent of Average Normal Rainfall in the Hyderabad Area

Month	Monthly Rainfall at ICRISAT	Percent of Average	30-year Average Rainfall Hyderabad Area
	mm	%	mm
April	—	—	24.0
May	3.0	11	26.5
June	62.4	54	115.5
July	161.0	94	171.5
August	230.8	147	156.0
September	68.9	38	181.0
October	216.4	324	67.0
November	10.6	45	23.5
December	1.3	22	6.0
January	—	—	5.5
February	—	—	11.0
March	—	—	12.5
Totals	754.4	94.0	800.0

Total rainfall was slightly below normal this year. The major difference between rainfall this year and previous years was a shift in the peak rainfall months. August and October had the highest rainfall; normally July and September are the peak months. While this resulted in a generally favorable growing season during the kharif and gave a good start to rabi crops, late rains caused some harvesting problems of monsoon crops.

Temperature. The highest temperature recorded at the Government of India Department of Meteorology station at Hyderabad was 43.3°C. on two dates, 30 April and 10 May 1973. The minimum of 9.3°C. occurred on 6 January 1974.

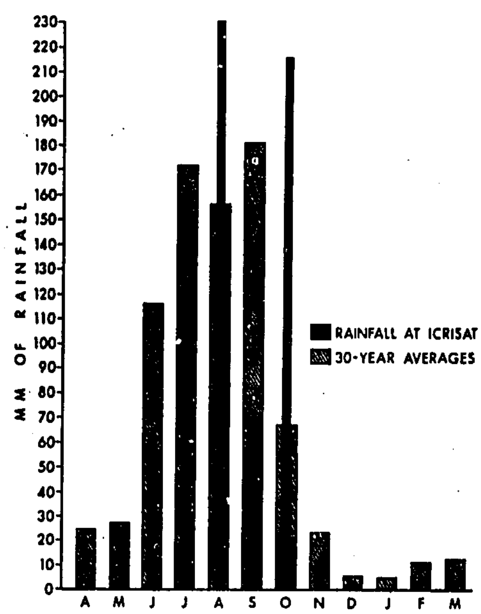
Wind. Crops were damaged by strong, dry winds in June. The maximum average wind velocity recorded at the ICRISAT weather station over a 24-hour period was 41-km/hr. This maximum occurred on 15 June 1973. Instantaneous velocities reached 60 to 70-km/hr.

Evaporation. A maximum daily evaporation of 19.6-mm was recorded on 19 June 1973, while the pan evaporation from 15 June 1973 to 31 March 1974 amounted to 1744-mm.

Soil Temperature. Soil temperatures taken at depths of 100 and 150-cm ranged between 25° C. and 32° C.

Dew. Small amounts of dew were recorded from October to January. A maximum value of .35-mm/night was recorded on 8 November 1974.

Figure 1. Comparison of the 1973–74 Monthly Rainfall at ICRISAT with 30-Year Averages for the Hyderabad Area



SUMMARY OF RESEARCH HIGHLIGHTS

CROP IMPROVEMENT

Sorghum

Applied breeding program. A brief description of the 12,693 lines of sorghum obtained in 1973–74 is given in Tables 2, 3 and 4. Initial steps in the applied breeding program involved formation of a regional nursery. Diallel crosses from the All-India Coordinated Sorghum Improvement Project (AICSIP) provided outstanding selections.

We chose 116 lines from kharif plantings for an elite nursery; mean row yield was 3,010-kg/ha. Bird resistant types from the CIMMYT high altitude nursery and selections from the 439 ALAD program lines were put into yield trials.

Population and protein breeding. Recurrent selection began on 33 composite populations. Selected composite populations are described and yield data from several are presented in Table 5. We began selection and yield trials of the Purdue and Nebraska composites and started a new composite from the AICSIP materials. The Downes population from Australia contained few steriles, so we will continue random mating for a few generations. The West African populations performed better in the kharif than rabi season due to the many photoperiod-sensitive genotypes they contain.

Selection on the remaining composite populations emphasized shorter, photoperiod insensitive plants with desirable grain and agronomic characters. We are testing high lysine lines from Purdue and Ethiopia and will form composites from these materials.

The newly formed biochemistry and nutrition laboratory and physiology support unit will be making contributions to the sorghum and other crop improvement programs.

Entomology and pathology. Of the 11 insects identified this season, the shootfly, *Atherigona soccata* (Rond) poses the most serious threat to sorghum. We tested several insecticides and have begun investigations on resistance. Six diseases were identified this year and screening for resistance to grain mold was started.

Pearl Millet

Applied breeding program. We made a preliminary assessment of this year's 6,612 germplasm entries for (1) maturity, (2) head character, (3) height and (4) disease reaction. Description of entries is given in Table 7. Hybridization, inter-varietal crosses and development of synthetics received primary attention. Results of a yield trial of 20 hybrids from the All-India Coordinated Millet Improvement Project are summarized in Table 8. Ten lines of male sterility were multiplied during the kharif. Three male steriles were crossed to 904 selected inbred lines. We made 170 crosses in the intervarietal program. The synthetics program is in initial stages.

Population breeding. Grain yield trials of the East African composites are summarized in Table 9. We began development of four new composites, three based on length of maturity and one combining dwarf lines. The early maturing composite has 194 entries; the medium maturing, 196; the late maturing, 45; and dwarf, 86. Nutritional quality will receive increasing attention as our laboratory develops.

Entomology and pathology. Seven insects were identified on the three millet crops grown this year. Insects have not been a serious threat to pearl millet. Rust, downy mildew and ergot are serious diseases of millet. We have some indications that genetic resistance exists in some lines and will explore this further.

Chickpea

Germplasm. The 4,709 lines supplied to us this year by Indian scientists launches the first systematic, international effort to gather the chickpea germplasm resources of the world. An additional 1,249 lines originating from 30 different countries were added by the end of the year. Table 10 identifies the countries and lines banked from each. Morphological and yield character observations revealed wide variations in plant height and spread, pods per plant, seeds per pod, etc. Color and seed weight also varied considerably.

Applied breeding program. We made 423 crosses this season seeking improved yield and combinations of high yield components. More than 100 crosses were related to maturity, seed size and seed color objectives. We studied the relationship of emasculation to time of day and pollination plus other variables related to crossing techniques (Tables 11 and 12).

Entomology and pathology. The grain pod borer (*Heliothis armigera* Hb.) damaged every chickpea line. We found effective chemical controls this year and will investigate genetic resistance. Wilt pathogens from six areas were collected in India for pathological investigations in subsequent years. Blight (*Ascochyta rolfsi* and *Sclerotium sclerotiorum)* and rust *(Uromyces* sp) will also receive attention.

Pigeonpea

Germplasm. We obtained 3,439 cultures from the Americas, Africa and Asia. Recorded observations revealed wide variations in plant height and width, number of branches, number of seeds per pod; seed weight and time from planting to floral initiation (Table 13).

We conducted an extensive survey and collection trip in Madhya Pradesh and found pigeonpea growing under very diverse field conditions.

Applied breeding program. An initial effort was launched to obtain bold-seeded, early-maturing varieties and high-yielding varieties. We began investigations of the extent of cross-pollination and a study of photoperiod sensitivity using off-season plantings.

Entomology and pathology. Pod borers, the main pigeonpea insect pest in India, damaged 60 to 100% of pods in our germplasm cultures. Two lines, Sharda and culture No. 1861, had less damage. Four pod borer species and seven other insects were identified. Three insecticides were tested; Thiodan 35 gave effective control against borers.

While no disease problems were widespread or seriously damaging, five pathogens were identified. *Fusarium oxysporum* f. udum (Butler) caused wilt in four lines.

FARMING SYSTEMS

Production Factor Research

Intercropping. Planting two crops together offers a means of maximizing water use and overcoming land preparation problems associated with second-season crops. Pigeonpea was intercropped with mungbean, soybean, safflower and finger millet. We compared solid planting, alternate rows and alternate paired rows. In all cases, the paired row method produced significantly higher yields of both pigeonpea and the companion crop (Tables 14 and 15).

Pigeonpea was also intercropped with pearl millet. Again, paired rows gave higher yields than alternate rows or solid planting.

The pearl millet was ratooned in these trials, following a harvest sequence of fodder-fodder-grain (Tables 16 and 17).

Relay cropping. Planting a second crop before harvest of the kharif crop is another means of maximizing use of residual soil moisture and overcoming post-monsoon land preparation problems. We studied the effects of time of planting safflower and chickpea into a standing kharif sorghum crop. Time of planting relative to sorghum harvest had little effect on safflower or chickpea yield under this year's conditions (Table 19).

This study also examined effects of kharif fallowing and supplemental water treatment. A 5-cm supplemental irrigation produced significantly higher yields in both safflower and chickpea (Table 20). Fallowing during the monsoon season produced no yield benefits in subsequent crops. The loss of a kharif crop plus the cost of weed control and erosion losses suggest the widely-practiced system of kharif fallowing on black soil is economically questionable.

Pearl millet ratooning. Successive harvests of grain, stalks or green fodder can be taken from pearl millet because of its ability to grow back through profuse tillering. We tested six harvest systems involving one or more grain crops, as many as five green fodder crops and various combinations of the systems. Results were inconclusive (Tables 21, 22 and 23), but the study demonstrated that ratoonability adds a degree of versatility that might be useful during a monsoon drought.

Method of planting. Ridge planting is one practice associated with our soil and water management investigations. To determine the production impact of the system, we conducted a trial comparing ridge to flat planting with sorghum, pearl millet, sunflower and pigeonpea. Response to nitrogen fertilizer was also recorded.

Method of planting was not significantly related to yields. Most variation was due to nitrogen fertilization (Table 24). Ridge planting on red soils resulted in sandblast damage.

Fertilization. Chemical fertilizers have been used very little in rainfed farming in the semi-arid tropics. Two years of fertilizer response observations have helped to provide information for designing further experiments involving diverse crops, soils and management systems. We are seeking knowledge of underlying principles related to use of chemical fertilizers under the characteristic rainfall conditions. Response observations are reported for several kharif and rabi crops for two years on both red and black soils (Tables 25–29).

Kharif irrigation. We are investigating "life-saving" applications of water during a monsoon drought as one way of using harvested runoff water to stabilize agricultural production in the semi-arid tropics. The favorable rainfall distribution during the 1973 kharif resulted in inconclusive response data (Table 30). Further studies are required.

Root sampling. To determine which plant species show the greatest root exploration and the effects of management systems on rooting behavior, we started preliminary studies of the rooting pattern of seven major crops. The variation is recorded in Tables 31–35 and illustrated graphically in Figures 23–27. These data will assist in design of future experiments correlating root distribution and water absorption.

Resource Management Observations

Observations on resource management involved a monitoring of experimental features of improved farming systems on several natural watersheds in the black soil area. The ridge and furrow system effectively manipulated runoff, reduced drainage problems and erosion and increased infiltration (Table 36, Figures 34–36). Grassed waterways were found to be an efficient means of carrying runoff with minimal erosion loss. Preliminary trials of grasses revealed several species provide effective cover combined with reasonably high production (Figures 39 and 40).

Experimental design of a small, comparatively deep pond with a favorable surface area to volume-stored ratio (Figures 41 and 42) resulted in minimal evaporation and seepage losses (Table 37). Comparisons of total alternative systems on a production basis demonstrated a potential for increasing yields several fold over present production in the semi-arid tropics.

Preliminary work on the water balance has moved us closer to answering key questions about the optimal use of basic resources in the semi-arid tropics. We estimate an overall rainfall use efficiency of about 70% on the improved experimental watershed versus 50% for a traditional rabi cropping system.

Answers to some of the very basic questions being explored in the resource management phase are vital to development of the integrated, productive and stable farming systems necessary to improve the quality of life for the people of the semi-arid tropics.

Common Names of ICRISAT's Four Crops

Language	*Sorghum vulgare*	*Pennisetum typhoides*	*Cicer arietinum*	*Cajanus Cajan*
English	Sorghum, Durra, Milo,Shallu, Kafir Corn, Egyptian Corn, Great Millet, Indian Millet.	Pearl Millet Bulrush Millet Cattail Millet Spiked Millet	Chickpea, Bengal Gram, Gram, Egyptian pea, Spanish pea, Chestnut bean, Chick, Caravance	Pigeonpea Red Gram
French	Sorgho	Petit Mil, Millet Mil a Chandelles	Pois Chiche	Pois Cajan
Spanish	Sorgo Zahina	Milo Perla Millo	Garbanzo Garavance	Gandul
Hindi	Jowar	Bajra	Chana	Arhar, Tur

PART 1. CROP IMPROVEMENT

THE CEREALS

Sorghum *(Sorghum vulgare)*

Pearl Millet *(Pennisetum typhoides)*

THE PULSES

Chickpea *(Cicer arietinum)*

Pigeonpea *(Cajanus cajan)*

THE CEREALS

Sorghum *(Sorghum vulgare)*
Pearl Millet *(Pennisetum typhoides)*

Sorghum and millet are the dominant cereals grown under the chancy rainfed conditions of the semi-arid tropics. Together they occupy more than 70-million hectares. They are staple cereals for many millions of persons who live in the areas of adaptation.

High-yielding varieties and modern technology packages have brought rice and wheat their quantum leaps in productivity. Neither the practices developed over a thousand years, nor the limited research attention yet paid to sorghum and millet in the tropics, have triggered the kind of increase needed to turn the worsening trend of per capita calorie supplies or ease the increasing protein-calorie malnutrition in heavily populated developing nations.

ICRISAT Goals

The long-term effects we expect to stimulate through the cereals breeding program include:

- Consistent improved performance of cereals over a wide range of environments of the semi-arid tropics.
- Genotypes that have higher yield potential than found in the cultivated varieties now available.
- Improved resistance to insects, diseases and such specific enemies as witchweeds.
- Grains that, in addition to higher yield, have improved nutritional value and the palatability plus cooking qualities desired by users.

We are pursuing these goals both at our Hyderabad location and in other regions. This first year in the breeding program, we emphasized accumulating and assessing breeding material. Also, some time was devoted to establishing links with cereals breeders throughout the semi-arid tropics.

Our approach is to assemble and to develop the genetic materials that permit plant scientists in national programs to develop better varieties needed by the agriculture they serve. If outstanding varieties result in our breeding work here, they will also be available to the regions that can use them.

The Conditions at Hyderabad

ICRISAT has a wide range of environments. Both red and black soils—two of the three great soil types of the semi-arid tropics—are represented here. There are three growing-season environments: (1) Kharif, or monsoon season, lasts for the duration of the rains, generally June through September; it has long days until the September equinox. (2) Rabi, or dry season, is cooler with shorter days and very little rainfall. During rabi, crops are supported by residual soil moisture or irrigation. (3) A summer season with high temperatures at flowering time permits short-season materials to be grown with irrigation. Also available are saline soils and soils with impeded drainage. We can superimpose high and low fertility levels and also shoot-fly infestation.

SORGHUM IMPROVEMENT

Three distinct approaches are included in our sorghum improvement work. We are gathering, maintaining and screening a collection of world germplasm resources; we are involved in a program for immediate development of useful genetic material; and an extensive back-up program of composite population development is underway.

GERMPLASM

Three groups of germplasm accessions were obtained in 1973–74: 33 composite populations; 7,494 lines of segregating or heterogeneous material; and 5,166 elite lines, world collection entries and new accessions. Tables 2, 3 and 4 give some detail about the ma'erials that were grown here this year.

We received 13 requests from sorghum breeders for seeds from our collection, with enquiries from all continents except North America.

Figure 2. ICRISAT Cereal Breeder Dr. Hugh Doggett examines sorghum germplasm.

APPLIED BREEDING PROGRAM

Regional nursery. A first step in the immediate applied program was to form a regional nursery. Promising lines were chosen for the nursery which will be distributed in 1974 to other plant breeders who can grow and observe them under their conditions.

AICSIP diallels. The outstanding source of good selections was three diallel crosses from the All-India Coordinated Sorghum Improvement Project, at nearby Rajendranagar. Forty-five parent varieties contributed to these diallels: one group chosen for yield and desired agronomic characters; one group for resistance to sorghum shoot-fly or stem borer; and the third group for grain quality—good protein and lysine levels and desired color and endosperm type.

Elite nursery. We selected 680 plants from 712 kharif plots for an October planting on red soils and November planting on black soils. In both rabi plantings, 116 lines were chosen for an elite nursery. Some early-maturing lines were put into a 5x5 lattice yield trial in a summer planting. Mean row yield for the 116 lines was 3,210-kg/ha.

CIMMYT high altitude breeding nursery. A high altitude breeding nursery from CIMMYT contained early maturing entries—the grains are mainly the brown, "bird resistant" type that is unpopular with most peo[illegible] who eat sorghum. From 2,462 entries grown in the kharif, we selected 700 for the rabi season plots. The best material from those went into a 5x5 lattice yield trial grown in the summer season. The trial had not been harvested at the end of our report year.

ALAD materials. A collection of 1,471 lines of the U.S.A. agronomic type—supplied from the Arid Lands Agricultural Development (ALAD) program in Lebanon—were

Table 2. Sorghum Germplasm Accessions, 1973–74—Composite Populations

Source	No. Designation	Materials Incorporated	Sterile Source
W.M. Ross, Kansas, U.S.A.	1 KP1 Br	U.S. sorghums	al
W.M. Ross, Nebraska, U.S.A.	7 NP1-NP6, NP8	U.S., African and conversion program material, separated into maintainer and restorer populations	ms_3 with ms_c in NP 1
	1 Ross 4 n	Tetraploid grain type	none
J. Axtell, Purdue Univ. U.S.A.	5 PP1-PP3, PP5 PP6	NP2B and NP3R crossed with 174 elite World Collection entries evaluated for protein, lysine, quality and agronomic character	ms_3
D.J. Andrews Nigeria	1 WABC 1 Bulk Y	Nigerian and exotic stocks of medium or short height with good grain quality	ms_7
J. Kern, EAAFRO Uganda	2 RS/A and RS/R	Good lines developed at Serere, with good exotic stocks, maintainer and restorer	ms_3
	2 Collection Restorer Collection Non-restorer	Broad based World Collection entries, containing some 1,200 entries in all	ms_3
	3 Ethiopian High altitude H.A. Maintainer	High altitude sorghums from Ethiopia, W. Uganda and W. Kenya, with the basic components of RS/R	ms_3
	3 Good Grain I Good Grain II Red flinty	85 lines with varied grain shapes, sizes, and textures, but mostly white or yellow with corneous endosperm	ms_3
	1 RS5DX	Best Serere bred lines	ms_3
	1 RS5DXCSF	Shoot-fly resistant lines	ms_3
	1 RS1 x VGC	Elite collection entries x RS/R	ms_3
	1 Hybrid RS	Best hybrids of U.S. steriles x Collection entries at Serere	ms_3
	1 Puerto Rico	Second backcross of Conversion Program	ms_3
N.G.P. Rao AICSIP, India	1 R. Composite	Good lines in Indian program x RS/R	ms_3
R.W. Downes, Australia	1 Downes Composites	Sorghums drought tested in Australia	ms_3
TOTAL	33		

grown in kharif. We selected 439 lines for October plantings, with 36 put into the elite nursery for growth in the rabi season. The best went into the summer yield trials.

POPULATION BREEDING

Composite program. We applied recurrent selection methods in using the 33 composite populations this year. Table 2 indentifies the composites. We planted the composites in the kharif and selected best progenies from those matings of the many genetically different plants in each. In the rabi season the seeds from those selected individual plants were grown in progeny rows. Table 5 summarizes the yield information from those progeny rows selected from

Table 3. Sorghum Germplasm Accessions 1973–74—Segregating and Heterogeneous Material

Source	No. of Lines	Materials Incorporated
N.G.P. Rao, AICSIP, India	712	Segregates from three diallel crosses of good World Collection entries for yield, grain protein and quality, and pest resistance
	142	World Collection entries x ms_3 or ms_7 stocks
	100	Crosses and backcrosses of good agronomic types x borer or shoot-fly resistance
	367	Entomologist's nursery of intercrosses for shoot-fly and borer resistance
	900	Indian x Exotic crosses
	323	Intercrosses for yield and grain quality
Elmer Johnson, CIMMYT, Mexico	2,462	High altitude breeding nursery
S. King, Nigeria	264	Crosses involving Striga resistance
J. Kern, EAAFRO, Uganda	27	Mixed bulks of tetraploid grain sorghum
	549	F_2 and F_3 generations of crosses of elite lines
J. Axtell, Purdue Univ, U.S.A.	1,651	Crosses involving high lysine sorghum
J. Robledo, IRAT, Upper Volta	7	West African x exotic crosses F_2 bulks
TOTAL	7,494	

Kansas, Nebraska and Purdue populations. Figure 3 illustrates the data graphically.

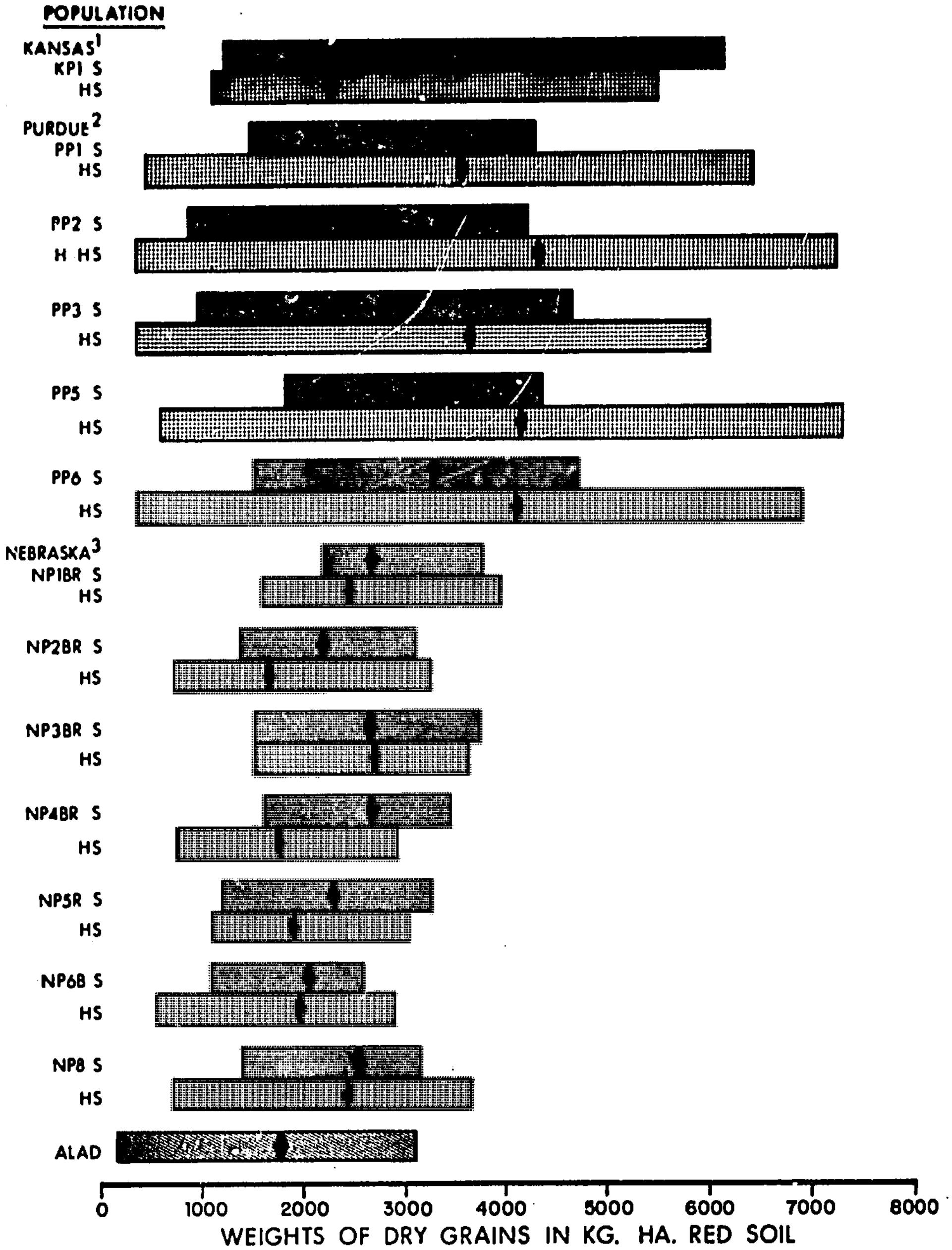
Purdue and Nebraska composites. The Purdue composite population showed good yield and vigor. It had a higher proportion of quality grains than did the Nebraska populations. In all these populations, we selected good fertiles in the half-sib rows, and we sibbed in S_1 rows to maintain a high frequency of ms_3 for recombination between selected rows. We put together a "fast lane" recombination generation from the Nebraska populations for a summer planting. We planted two replications for yield trials involving 64 selections of the pooled Nebraska maintainer populations and 56 selections from the Nebraska restorer populations. This summer planting had not been harvested at reporting time.

AICSIP composite. We started a new composite, drawing on the excellent material in the three diallel crosses from the All-India Coordinated Sorghum Improvement Project (AICSIP) at Rajendranagar. These crosses carry a broad genetic base with quality, yield and pest resistance. Entries from every family were emasculated and pollinated with bulk pollen carrying one of three male steriles. Phenomena such as the *Helminthosporium maydis* outbreak in the United States underscore our need to avoid a too-narrow cytoplasmic base. This composite has three sources of male sterility, with 1,006 crosses on 435 progeny rows. The pollinations were as follows: Ms_3ms_3, 347; Ms_7ms_7, 289; Al al, 370.

Table 4. Sorghum Germplasm Accessions 1973–74—Elite Lines, World Collection and New Accessions

Source	No. of Lines	Materials Incorporated
N.G.P. Rao, AICSIP, India	991	Elite lines
	1,172	World Collection entries
L.R. House, ALAD, Lebanon	1,471	Elite short straw entries, mostly of good grain quality
J. Marathee, CNRA, Senegal	8	Early lines with good grain quality
J. Kern, EAAFRO, Serere	150	Bulks of Elite EAAFRO lines
D.J. Andrews, Nigeria	16	Elite lines selected in Northern Nigeria
J. Axtell, Purdue Univ., U.S.A.	4	High lysine collections
	22	Elite lines
Brhane Gebrekidan, HSIU, Alemaya, Ethiopia	1,309	Ethiopian sorghum varieties, including collections from fields containing high lysine types
W. Young R.F., Thailand	23	Elite lines
TOTAL	5,166	

Figure 3. Yield Range and Means of Selected Sorghum Lines, Hyderabad, 1974.



TOTAL BAR REPRESENTS YIELD RANGE AND THE CENTER MARK REPRESENTS YIELD MEAN.

S=SELFED, HS=HALF SIB, YIELD BASED ON TABLE 5.

1 PLANTED NOV. 2, 1973

2 PLANTED NOV. 3, 1973

3 PLANTED OCT. 20, 1973

Downes population. The Downes population from Australia showed well. It contains few steriles, so we will continue random mating for a few more generations.

West African populations. West African populations performed well in the rabi season, showing good grain size on short, vigorous plants; performance in the kharif was hampered by the many photoperiod-sensitive genotypes they contain.

We grew the remaining composite populations as bulks in the kharif season, selecting heads for progeny rows in the rabi season planting. Our selections are emphasizing shorter, photoperiod-insensitive plants with desirable grain and agronomic characters. We expect to continue with mass selection; then to merge these populations

Table 5. Yields from Selfed and Half-Sib Lines from Selected Composite Populations, Hyderabad, 1974

Population		No. of Rows	Yield kg/ha	
			Range	Mean
Kansas[1]				
KP1	Selfed	49	1,200—6,080	2,930
	Half-sib	109	1,090—5,460	2,250
Purdue[2]				
PP1	Selfed	69	1,440—4,250	2,930
	Half-sib	194	430—6,380	3,530
PP2	Selfed	48	860—4,180	2,900
	Half-sib	176	360—7,200	4,280
PP3	Selfed	76	940—4,610	2,780
	Half-sib	388	350—5,970	3,610
PP5	Selfed	44	1,800—4,320	3,330
	Half-sib	298	580—7,270	4,120
PP6	Selfed	29	1,500—4,680	3,250
	Half-sib	199	350—6,840	4,060
Nebraska[3]				
NP1BR	Selfed	34	2,180—3,740	2,670
	Half-sib	124	1,560—3,950	2,480
NP2B	Selfed	31	1,350—3,070	2,150
	Half-sib	96	700—3,190	1,660
NP3BR	Selfed	18	1,510—3,690	2,640
	Half-sib	97	1,510—3,590	2,680
NP4BR	Selfed	19	1,600—3,430	2,670
	Half-sib	50	730—2,910	1,740
NP5R	Selfed	26	1,200—3,220	2,290
NP6B	Selfed	23	1,100—2,600	2,050
	Half-sib	107	580—2,910	1,980
NP8	Selfed	28	1,400—3,170	2,570
	Half-sib	87	720—3,640	2,440
ALAD[4]		500	210—3,120	1,800

[1]Planted Nov. 2, 1973—Red Soil Field R2
[2]Planted Nov. 3, 1973—Red Soil Field R2
[3]Planted Oct. 20, 1973—Red Soil Field R6
[4]Planted—Red Soil Field R6

and move them into the main program.

BREEDING FOR PROTEIN

High lysine—Purdue. We received two high lysine lines from Purdue University's Dr. John Axtell and colleagues. The lines, IS11167 and IS11758, are crossed with a wide range of breeding material. The 1,651 crosses and backcrosses involve those two lines with the Nebraska population, Purdue population and a yellow-endosperm composite developed by Dr. Bruce Maunder, of DeKalb AgResearch, Inc., in the United States. We shall develop a composite from this material which already contains ms_3.

High lysine lines grown here in our rabi season, planted on 23 Nov. 1973, have produced a shrunken mature seed. We have described it generally as a "sandwich of a large embryo between two layers of pericarp." The mature grains contain little endosperm and have a somewhat bitter flavor. (In Ethiopia, where the lines were found, custom is to eat the grains in the green stage, when they are well-filled and sweet.)

High lysine—Ethiopia. As another attempt to combine the high lysine characteristic with grain type that would be acceptable to farmers and consumers, we are working with 220 lines collected from farmers' fields in Ethiopia. Purdue's Dr. John Axtell and Dr. Brhane Gebrekidan, of Haile Sellassie University, made the collections in areas of Ethiopia near the source of the high lysine lines. The National Institute of Nutrition, Hyderabad, will conduct biological evaluations and feeding trials with grain from the high lysine selections.

CLOSELY RELATED INVESTIGATIONS

Cereals breeders can go only part of the way alone toward the yield and quality goals set for ICRISAT. A number of other scientists work as full members of the crop improvement staff. While all work as an integrated team, the special contributions from the closely related disciplines are highlighted separately.

Nutritional Quality

Our biochemistry and nutrition laboratory was staffed and equipped as the report year ended. Early work was concentrated on testing procedures and calibrating equipment.

Major emphasis focuses on quantity and quality of protein produced by the cereals in the breeding program. With tens of thousands of samples—three generations each year of two cereals—testing procedures provide an elimination process: Fast assay procedures identify the smaller number of samples that justify more precise tests, leading eventually to a relatively few samples that will be run through the four-hour test of the Beckman Amino Acid Analyzer (Figure 5).

The laboratory does not operate exclusively on cereals. Protein content and quality of the pulse crops are also measured by the same personnel and the same equipment.

Physiology

We took the first steps this year toward

Figure 4. ICRISAT Cereal Breeder David Andrews records observations on high lysine material.

establishing a plant physiologist's composite population, drawing on ideas developed by Dr. J.D. Eastin and Dr. C.Y. Sullivan at the University of Nebraska. Plant types that are more efficient in the semi-arid tropics need to be developed.

We studied three main physiological characteristics of sorghums: (1) seed and embryo size, (2) length of grain filling period, and (3) reduction in leaf number between floral initiation and flowering. Ten plants each of 148 World Collection entries were included: entries represented large, medium and small seeds and either hard or soft endosperm.

This first year of measurement and observation revealed these characteristics:

- Differences existed in the position of the largest leaf in relation to the flag leaf. The differences should correlate with stages at which floral initiation occurred.
- Environmental conditions—presumably temperature and moisture—affected the length of grain filling period within varieties.

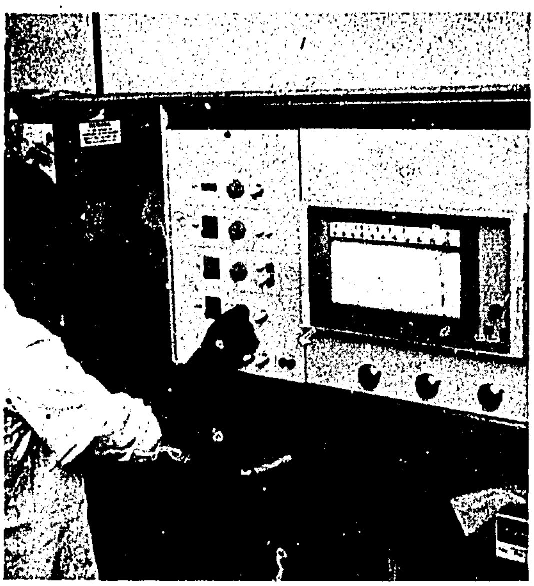


Figure 5. ICRISAT Biochemist Dr. S.P. Yadav analyzes samples for protein.

- Larger grains tended to take longer to fill, although a wide range in grain filling period was recorded for each seed size. Table 6 summarizes the grain filling and grain size data.

Entomology

Insect identification. We identified eleven insects in the sorghums this season. Four additional, unidentified ear bugs were seen. Spider mites and rats caused some damage at various stages of crop growth. The identified insects were:

Shoot-fly, *Atherigona soccata* (Rond)
Stem borer, *Chilo zonellus* Swinh
Pink stem borer, *Sesamia inferens* Wlk
Sorghum midge, *Contarinia sorghicola* Coq.
Gram caterpillar, *Heliothis armigera* Hb
Aphid, *Rhopalosiphum maidis* Fitch
Grasshopper, *Cyrtocanthacris tatarica* (L.)
Bugs: *Nezara viridula* L, *Dolycorsis indicus* Stal, *Bagrada cruciferarum* Kirk, *Dysdercus* sp.

Treatment. Several insecticides were tested during the season, either singly or in combination. Furadan 3G at 3-grams per meter along the row was effective against shoot-fly. Endrin granules (2%) put in the whorls at 30 and 45 days gave good results against stem borer (Figure 6). Sprays of Thiodan (0.07%) plus Sevin (0.2%) at 10-day intervals controlled midge well.

Growth effect of Furadan. We observed a phenomenon related to Furadan treatment. Marked differences in growth occurred between many treatment and non-treatment rows *in the absence of shoot-flies*. We did not see this difference universally; some lines grew equally well in the absence of the chemical.

Shoot-fly resistance. We had planned to screen for shoot-fly resistance in breeding materials by treating half the rows with insecticide. But shoot-fly population was too low to justify selection on that basis. A few of the insects appeared in October plantings and none were present on the January

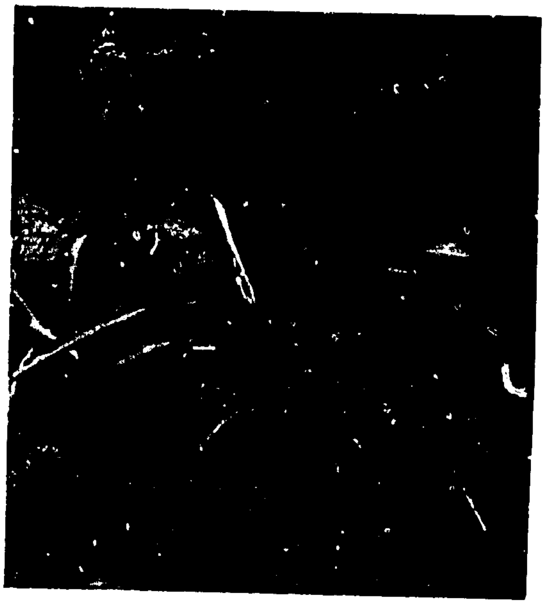


Figure 6. Typical stem borer damage on sorghum.

plantings. Only late-sown materials of July through September plantings and some plants held back by zinc deficiency or other cause failed to escape the shoot-fly.

Spider mites, *Oligonychus indicus* (Hirst), and rats caused damage at various stages of crop growth.

Pathology

We identified these six diseases in the sorghums this year:

Downy mildew, *Sclerospora sorghi* (Kulk) Weston & Uppal
Head smut, *Sphacelotheca reiliana* (Kuhu) Clint.
Sugary (or honeydew) disease, *Sphacelia sorghi* McRae
Grain smut, (Link)
Leaf blight, (Pass)
Rust, (Puccinia)

There was moderate incidence of downy

Table 6. Grain Filling Period in Relation to Seed Size of 148 Sorghum Varieties, Hyderabad, 1974

Grain Filling Period and Seed Characteristics	Seed Size								
	Large Seed n = 46			Medium Seed n = 48			Small Seed n = 54		
Grain filling period*	mean range	39.2 ± 32.3—	2.7 44.6		38.1 ± 30.2—	2.6 44.1		36.5 ± 30.5—	2.1 41.0
1,000 seed weight (g)	mean range	40.5 ± 35.0—	3.3 58.0		31.1 ± 28.0—	1.4 34.0		23.7 ± 12.0—	2.6 28.0
1,000 seed volume (cc)	mean range	33.0 ± 35.0—	3.0 50.0		26.0 ± 25.0—	2.0 30.0		19.0 ± 10.0—	2.0 25.0
Weight of seed per head (g)	mean range	38.2 ± 8.5—	14.8 77.5		37.4 ± 13.7—	9.3 73.3		34.4 ± 6.7—	10.4 81.3
Seed per head (no.)	mean range	950 ± 210 —	360 2,060		1,200 ± 760 —	330 2,550		1,440 ± 490 —	400 2,650

* Days from flowering to black layer formation

Planted Nov. 23, 1973
Grown on black soil (field B8)

mildew in the kharif season, but the frequency of the other diseases was very low.

We screened for resistance to grain mold in the kharif season; some brown grains showed good resistance, white grains generally did not.

LOOKING AHEAD IN SORGHUM IMPROVEMENT

Constraints. Two principal constraints shape our strategy for handling ICRISAT breeding populations: (1) fitting the seasons—some early-maturing types can produce three generations in a year; and (2) producing plenty of seed so the testing generation can be grown in a wide range of environments.

Four-generation cycle. Consultation with Statistical Geneticist Dr. S.A. Eberhart, USDA collaborator at Iowa State University, helped establish a four-generation cycle that should move our program rapidly without violating the constraints. This is the plan:

- Rabi 1 — Recombination and selection of sterile heads
- Kharif 1 — Half-sib testing; maturity, height, agronomic and disease factors
- Rabi 2 — S_1 testing: grain quality, protein, lysine, disease and insect resistances.
- Kharif 2 — S_2 testing: yield and adaptability over wide range of environments. Sibbing within plots.

Testing environments. The ICRISAT experiment station will provide a number of the environments needed for testing: no fertilizer to high levels of fertility; presence and absence of shoot-fly and borer; and red and black soils.

Inoculum levels are low at the home site, so natural disease complexes for testing are not available; the pest and witchweed (*Striga*) complexes at Hyderabad are not the same as those occurring in Africa. Some environments can be simulated with disease and pest nurseries. We anticipate broadening test conditions by cooperation with research centers throughout the semi-arid tropics. We hope to arrange some tests which will be done in farmers' fields.

The Nebraska and Purdue populations will be merged to give four populations; designated NBP, NPR, PPB and PPR. We may combine the four later into two, B and R.

PEARL MILLET IMPROVEMENT

GERMPLASM

The first planting for kharif 1973 included 2,673 germplasm entries. By the time of rabi plantings, 27 September 1973, 564 more had been obtained. And at the end of March 1974, we had 6,612 pearl millet entries. Table 7 gives the sources and some description of the principal collections.

This year's work with the germplasm included selfing of all entries, although we have not reached a final strategy on how best to maintain the germplasm being "banked" here.

We assessed the entries this year for (1) maturity, (2) head characters, (3) height and (4) disease reaction. We recorded a wide range of head types and grain types. Some lines have resistance to downy mildew and leaf rust.

Plant breeders from Brazil, South Africa, England and India requested seeds. We supplied seeds of 175 lines or hybrids.

BREEDING GOALS

The objectives cited for cereals improvement at the start of this section apply equally to pearl millet. Disease resistance may demand even greater concern with millets, while pest resistance may be less important than with sorghum.

Table 7. Pearl Millet Germplasm Accessions, 1973–74

Origin	Place or Agency	Number of Entries	Type of Material
India	Jamnagar	767	From original All-India Project World collection (IP numbers)
		1,004	Promising inbred lines
		3	Hybrids
	Maharashtra	101	Promising lines
	Mysore	71	Disease-tolerant lines
	IARI, New Delhi	214	Disease-free lines
		1,200	Promising lines from All-India Project
		15	Promising hybrids
	Ford Foundation	689	Duplicate IP entries
Thailand	Bangkok	264	Duplicate IP entries screened and multiplied in Thailand
Uganda	Serere	34	Varieties and lines from Beirut
		8	Composite populations developed at Serere
Nigeria	Samaru and Kano	210	Promising lines
		3	Composites developed in Nigeria
Lebanon	ALAD	18	ALAD varietal collection
		2,000	African collection and improved material from CNRA, Bambey, Senegal
United States	USDA Tifton, Ga.	11	Newly developed cytoplasmic male sterile lines
TOTAL		6,612	

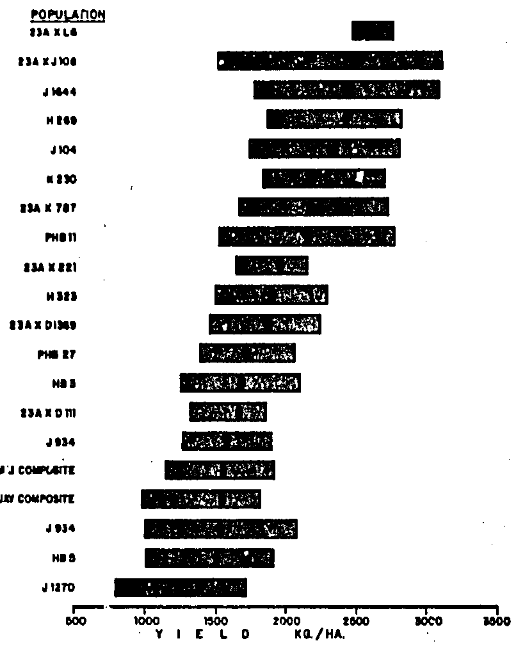
Environments available at ICRISAT permit three generations of pearl millet in a calendar year. Selection for good seed set under high temperatures may be particularly useful in millets that perform well in the summer season. (Temperatures ranging from 40 to 43°C. are typical during much of April and May at Hyderabad, as in many other millet-producing areas.)

APPLIED BREEDING PROGRAM

Our immediate program follows three main breeding routes that we believe will achieve early results: hybridization, inter-varietal crosses and development of synthetics. Our efforts are built on a strong base provided by improved genotypes from two outstanding programs: the All-India Coordinated Millet Improvement Project (AICMIP) at New Delhi, and the Centre National de Recherches Agronomiques (CNRA) at Bambey, Senegal.

Hybrids. During the kharif season 1973, we grew a yield trial on black soil involving

Figure 8. Yield Range and Means of 20 Pearl Millet Hybrids from AICMIP, Hyderabad, 1973



TOTAL BAR REPRESENTS YIELD RANGE AND THE CENTER MARK REPRESENTS YIELD MEAN. DATA BASED ON TABLE 8.

20 hybrids of the AICMIP group. Table 8 and Figure 8 give the yield results, showing a range of just under 1,400 to over 2,500-kg/ha (with a least significant difference of 550-kg/ha).

Ten lines with cytoplasmic male sterility were multiplied in our kharif season. These included four received from Dr. G. W. Burton of the United States Department of Agriculture program at Tifton, Georgia; four from Punjab Agricultural University in India; one from Gujarat Agricultural University at Jamnagar; and one developed from African material at Serere, Uganda.

During the rabi season, we made 904 crosses from selected inbred lines to three male steriles:

18D2A	325
23D2A	423
23DA	156

The resulting F_1 hybrids were tested in

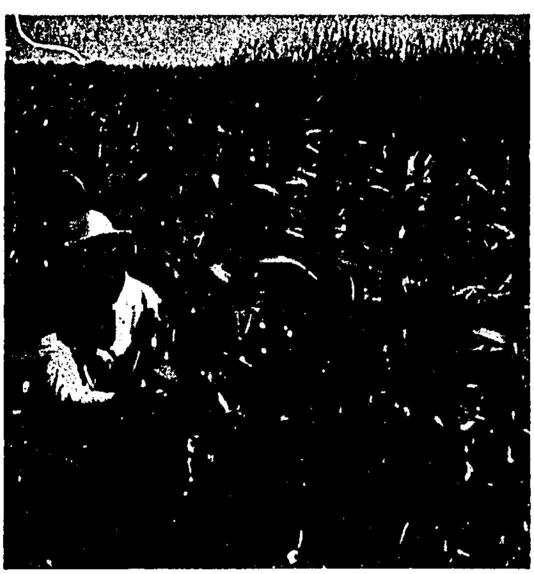


Figure 7. ICRISAT Cereal Breeder J.V. Majmudar reviews pearl millet performance.

the summer season, which was not over before the end of our reporting period. Among preliminary observations, we can report:

- 23D2A combined well with African varieties—14 hybrids yielded over 4,000-kg/ha.
- A number of hybrids showed reduced seed set under difficult environment, which makes them vulnerable to ergot disease.
- Some reduction of seed set may have been due to lack of pollen—the windward side of the head set more seed than did the leeward side.

Intervarietal crosses. Female steriles are not available to improve the economics of producing broad-based hybrids from intervarietal crosses. However, 170 crosses were made this year to observe varieties that combine to produce vigorous progeny. The crosses involved Indian and African lines and varieties, crossed during the rabi season and tested during the summer. Another purpose for this crossing was to transfer desired characters from African material, so we can select for good characters of both in the segregating generation.

Synthetics. Producing synthetic varieties may offer the quickest means of obtaining useful genetic materials in pearl millet. A few good inbreds can be intercrossed freely to form a new variety. This can be done in five generations or in two years with the potential of producing three generations per year.

This program will be activated when the best lines in our breeding materials have been identified.

POPULATION BREEDING

Population breeding techniques applied to pearl millet offer benefits similar to those achieved with other cross-pollinating crops. Since this program was started in rabi and summer seasons of 1973–74, it will take a few more years to produce improved materials.

Eight African composites were included in a grain yield trial in kharif 1973. Table 9 gives the results.

New composites. We began the development this year of four new composites, three based on length of maturity and one combining dwarf lines. Development began with visual screening of our rabi plantings—some 2,673 lines. The best 521 were divided on basis of maturity or straw length to form the four composites:

Table 8. Yield Trial of 20 Hybrid Pearl Millet Entries from the All-India Coordinated Millet Improvement Project Conducted at ICRISAT, Hyderabad, 1973

Entry	Yield (kg/ha)	
	Range	Mean
23AxL6	2,440—2,750	2,550
23AxJ 108	1,490—3,090	2,460
J 1644	1,750—3,070	2,420
H 269	1,840—2,810	2,410
J 104	1,720—2,800	2,330
K 230	1,820—2,680	2,160
23Ax787	1,640—2,710	2,160
PHB 11	1,510—2,760	2,150
23Ax221	1,630—2,150	1,940
H 323	1,480—2,290	1,890
23AxD 1369	1,440—2,240	1,870
PHB 27	1,380—2,050	1,700
HB 3	1,240—2,090	1,670
23AxD 111	1,320—1,850	1,650
J 934	1,260—1,890	1,570
Lam Composite	1,150—1,910	1,550
Vijay Composite	980—1,820	1,530
J 934	990—2,080	1,520
HB 5	1,000—1,890	1,510
J 1270	800—1,720	1,380

L.S.D. ($p = 0.05$) = 550-kg/ha
C.V. = 21.5%

Planted July 9, 1973, Black Soil Field B 8

Fertilizer: N, 80-kg/ha; P_2O_5, 40-kg/ha

Early maturing composite (EC): Heading in less than 45 days.

153 Indian entries
28 Good exotic entries—each entered twice
13 Excellent exotic entries—each entered three times

194 Entries

Medium maturing composite (MC): Heading in 45 to 55 days.

141 Indian entries
22 Good exotic entries—each entered twice.
33 Excellent exotic entries—each entered four times

196 Entries

Late maturing composite (LC): Heading in more than 55 days.

44 Indian entries
1 Sauna D_2 (exotic)—entered five times

45 Entries

Dwarf composite (DC): All maturity lengths.

69 Indian entries
17 Excellent exotic entries—each entered four times.

86 Entries

Random mating within the four groups began in the summer season of 1974. The method is that of M.N. Harrison, of Ireland, in which identity of each original entry is retained through the entire random mating program. (That is done by keeping the identity of each row, although pollination of the row comes from bulk pollen.) We plan to carry through four generations of random mating by this scheme and then to start recurrent selection.

CLOSELY RELATED INVESTIGATIONS

Entomology

Identification and treatment. Seven insect pests were identified on the three millet crops grown this year. Insects have not been serious threats to pearl millet so we have not made specific insect resistance part of the breeding program. Testing of genotypes under our wide range of environments and in the cooperating centers in other places should assure that our materials do not develop undue susceptibility.

Table 9. Yield Trial of African Composites of Pearl Millet, Hyderabad, 1973

Entry	Yield (kg/ha)	
	Range	Mean
Serere 2 M	2,350—2,720	2,610
Serere 3 M	1,860—2,540	2,120
Serere 1 (S) 4	1,890—2,140	2,000
Nigerian	1,820—2,280	2,000
Serere 10 M	1,010—2,620	1,790
Serere 14 M	1,250—2,020	1,760
Serere 13 M	660— 810	750
HB 3 (Indian hybrid)	2,020—3,760	2,700

L.S.D. ($p = 0.05$) = 800-kg/ha
C.V. = 23.7%
Planted July 10, 1973, Black Soil Field B 8
Fertilizer: N, 80-kg/ha: P_2O_5, 40-kg/ha

We identified these insects in millet plantings in 1973–74:

Stem borer (*Chilo zonellus* Swinh) was prevalent during the kharif season. We did not need to apply controls.

Earhead caterpillar (*Heliothis armigera* Hb.) was the most serious insect pest this season. We sometimes found four or five larvae feeding on a single earhead. Endrin at 0.04% gave good control.

The cabbage bug (*Bagrada cruciferarum*) may be a new pest of pearl millet. It causes damage by sucking sap from the leaves.

Other bugs identified were *Nezara viridula, Dolycoris indicus* and *Dysderus* Sp.

Aphid (*Rhopalosiphum maidis*)

Grasshoppers (*Cyrtocanthacris tatarica*)

Spider mites (*Oligonychus indicus*) which were controlled well with treatment of Kelthane.

As protection against the rust and earhead pests, we used combinations of Dithane Z – 78 + Sevin 50WP and Dithane Z – 78 + Endrin 20 ec.

Pathology

Rust, downy mildew, ergot and smut were the diseases observed in pearl millet plantings in 1973–74—in order of severity.

Rust. Rust (*Puccinia penniseti* Zimm) occurred in severe infestations in both kharif and rabi plantings. Symptoms appeared as early as ten days after planting: whole plants were covered with rust, as if coated with powder; leaves dried before flowering.

Opinion was that no line in the world germplasm had been reported free from rust infection. We made a rigorous search during the rabi planting for plants with rust resistance, finding one completely free from the rust, a Nigerian line, L 700481. Also, we found individual rust-free plants among other Nigerian lines and in lines and composites from Serere. These plants were selfed, and resulting individual heads were threshed separately and sown in the summer program. Rust incidence was negligible in the summer season, however, so we could not evaluate for rust resistance at that time. We have part of the seed of first selections and more from plants selfed again in the summer. These will be part of our kharif 1974 tests.

Downy mildew. Downy mildew (*Sclerospora graminicola* (Sacc.) Schroet) incidence was low in the 1973–74 plantings. Maximum infections occurred in the rabi plantings on male steriles 23A and 23D2A. We collected infected plants to get inoculum for a downy mildew sick plot (Figure 9). About 1.3-ha was devoted to multiplication of male sterile 5071 A which was produced by irradiation and has downy mildew resistance. This multiplication was carried out in cooperation with the All-India Coordinated Millet Improvement Project.

Ergot. Ergot (*Claviceps microcephala* (Walter) Tul.) infection was severe in our border rows of HB 3 and moderate in other breeding material and germplasm. We grew 71 lines received from Dr. K.M. Safeeulla, which were resistant to downy mildew and ergot under Mysore conditions. In our plots, 26 were infected with ergot, although all were free from downy mildew. All were susceptible to rust.

Smut. Smut (*Tolyposporium penicillariae* Bref.) was at low frequency throughout the year. In about 2-ha of germplasm, we found ten infected heads. We removed and burned those plants to prevent contamination of soil or seed.

LOOKING AHEAD IN PEARL MILLET IMPROVEMENT

Advances in nutritional quality of pearl millet should be helped along by the current screening of the world collection for crude protein and lysine content. That work is now underway in the Indian Agricultural Research Institute. Reports indicate a range of crude protein level from 10.2% to 23.0% and lysine content ranging from 0.90% to 3.46%. More effort will be devoted to nutritional quality of millet now that our laboratory has been established to routinely assay grains from research plots.

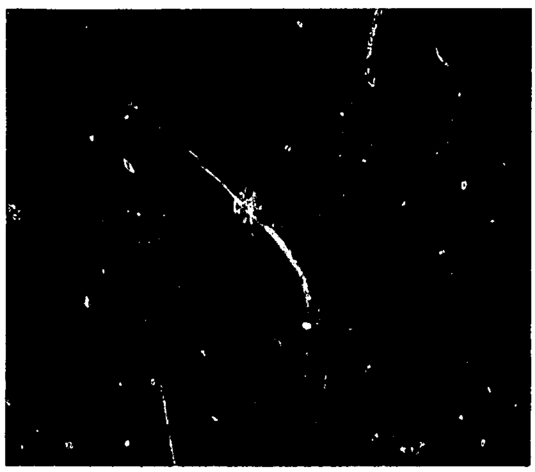


Figure 9. Characteristic downy mildew damage on pearl millet.

THE PULSES

Chickpea *(Cicer arietinum)*

Pigeonpea *(Cajanus cajan)*

World nutrition strategists cast grain legumes for an increasing role in the effort to reverse the worsening trend of protein nutrition for the world's population. For a host of reasons, animal proteins can only fill part of the gap which has widened with new successes in cereals technologies.

Our ICRISAT mandate embraces two of the grain legumes that now supply proteins to vast populations of the semi-arid tropics. Chickpea, third-ranking of the world's pulses, is grown annually on about 10 million hectares in Asia, Africa, Australia and Latin America. Pigeonpea is less widely distributed and covers less total area, but it is of major importance to millions of persons in India, where 2.3 million hectares are grown.

Most chickpeas and pigeonpeas are used as human food. Some are harvested as green peas-in-the-pod and consumed in that form. In India most of the crop is harvested as dry beans, split, crushed and prepared as dhal (a curry or puree).

Both pulses have protein totals in the range of 18 to 24 percent; both rate well on the amino acids that are inadequate in cereals, although they have a relatively low methionine content. When combined at about 20:80 ratio with rice, sorghum, millet, or wheat, these pulses provide an adequate and balanced protein-calorie diet.

The scientific history of chickpea and pigeonpea improvement is brief. Some trail-blazing work on chickpea was done in the middle East, at the Arid Lands Agricultural Development (ALAD) program in Lebanon; some attention had been focused on chickpea and pigeonpea in several Indian agricultural universities shortly before ICRISAT was launched. Neither crop has been the subject of the concentrated effort now possible.

ICRISAT Goals

We pursue two broad goals in improvement of these two pulses:

- We are assembling, maintaining and screening the world germplasm resources in chickpea and pigeonpea; we are furnishing seeds from our collection to plant scientists who have need of them.
- Through breeding programs, we seek to increase the ability of genotypes of both crops to produce: (1) higher yields, (2) optimum protein quantity, (3) desired protein quality and (4) favored consumer characteristics.

In managing the germplasm collections and the genotypes that come from our work, we will cooperate with plant breeders in national and regional programs. ICRISAT will be of most help by providing genetic materials that others may use in tailor-making lines needed for their specific situations. Therefore, we are giving attention to segregating genotypes with great diversity of genetic characters, including plant architecture, physiological attributes, insect and disease resistance, and many more. Neither pulse has been shown to be responsive to added fertilizer, and we are exploring this area of potential improvement; potential response to irrigation is another point of interest.

The Conditions at Hyderabad

The ICRISAT experiment station site includes two of the three great soils of the semi-arid tropics: the light, droughty red soils and the black soils with their greater water-holding capacity. We can thus carry out selection work in segregating materials as well as in final stages on soils widely representative of the areas we serve.

Climatic conditions at Hyderabad permit

a single generation annually of both chickpea and pigeonpea. We are establishing off-season nurseries of both crops, however, to reduce the time-lapse involved in crossing and growing out the necessary generations.

Three distinct "seasons" are available, and these conditions may be exploited as our pulse improvement work develops. The seasons are: kharif, the rainy season, which usually embraces June through September—long days until the September equinox; rabi, or dry season—with shortening days; And summer season with high temperatures (36 to 43° C for daily highs) during February through May.

CHICKPEA IMPROVEMENT

GERMPLASM

ICRISAT launched in 1973–74 the first systematic international effort to gather chickpea germplasm resources of the world. We began the year with 7,550 lines supplied by Indian scientists. After duplicate and triplicate entries were eliminated—and deducting lines that were lost due to failure to germinate—we had 4,709 lines. Before the end of the year, 1,249 lines from 30 other countries were obtained, most from the Ford Foundation's Arid Lands Agricultural Development Program in Lebanon. Thus as the second year of chickpea germplasm work was planned, the ICRISAT collection totaled 5,958 lines. Table 10 identifies the countries represented and the lines banked from each.

Observations 1973–74. We recorded this year a few morphological and yield character observations while growing out the 4,709 viable germplasms. Planting was late; therefore, some plant performance may not be truly characteristic.

Plants ranged in height from 16 to 66-cm. The plant spread range was from 14 to 128-cm.

Yield-related characteristics showed wide variations: Number of pods per plant varied from a few to a high of 383. (The large numbers of pods per plant were observed where plants were widely spaced, so we view these data with some reservations.) We observed 36 lines that bore two pods per peduncle (Figure 10). Fifty-two lines had four seeds per pod, though most lines fell within the range of 1.1 to 2.9 average seeds per pod (Figure 11). The 100-seed weight ranged from 5.7 to 44.5-grams, with the majority of lines falling between 12 to 20-grams.

These germplasm lines contain varied seed colors. Yellow testa color was observed most often. Other principal colors in descending frequency were salmon-white, black, green, brown plus a few odd colors.

Figure 10. Double podded chickpea line (left) is one yield-related characteristic under evaluation at ICRISAT.

Table 10. Countries of Origin of Chickpea Lines in the ICRISAT Germplasm Collection, 1973–74

Source	No. of Lines
Asia	
Afghanistan	17
Burma	9
Cyprus	14
Jordan	22
India	2,445
Iran	2,631
Iraq	16
Israel	11
Lebanon	17
Pakistan	44
Sri Lanka	3
Syria	9
Turkey	104
North America	
Mexico	137
United States	110
Africa	
Algeria	21
Ethiopia	9
Morocco	42
Nigeria	2
Sudan	3
Tunisia	17
United Arab Republic	62
Europe	
Bulgaria	1
Federal Republic of Germany	1
Hungary	3
Italy	3
Portugal	2
Spain	70
USSR	29
Yugoslavia	1
South America	
Peru	2
Not known	101
TOTAL	5,958

Next season we will step up observations on the 5,958 lines in our bank. Twenty morphological, yield and quality characters will be observed and evaluated. We will also score lines for resistance to wilt diseases and pod borers and for response to fertilizer and to irrigation.

Seed distribution. Seeds of a few varieties were supplied to plant breeders in Malaysia, Thailand and Sri Lanka. Many additional requests were pending at the end of the year. We plan to fill all requests to the extent possible based on the seed quantities available.

BREEDING GOALS

We pursue three principal goals to improve chickpea, all related to finding and developing:

- genetic materials with higher yielding ability
- genetic materials with improved nutritional quality
- genetic materials with effective resistance to diseases and insects.

While we may develop some varieties that merit direct release, we put most effort on providing the raw materials for national scientists throughout the world to enhance their breeding programs.

Table 11. Seed-Set Percentages According to Time of Day that Flower Was Pollinated, Hyderabad, 1974

Time of Day	Percentage of Seed-Set
0800 to 1000 hours	19.7
1001 to 1200 hours	21.4
1300 to 1500 hours	21.2
1501 to 1700 hours	23.1
Average temperature:	20.6°C
Average relative humidity:	59.8%
Average hours of sunshine:	10.4

APPLIED BREEDING PROGRAM

First series of crosses. In our first season of breeding work, we made 423 crosses. Each cross produced some seed, with a range from a single seed n one case to 261 seeds in another. Most produced the ten seeds considered sufficient to yield 4,000 F_2 seeds.

Among the 423 crosses were:

- A top-cross with four testers and 44 parental lines. Each of the testers excels in at least one yield component.
- Four diallel sets: One for yield and adaptation for high yield combining components; one for increasing the number of pods per plant; one for improving the harvest index; and one for developing bold seed with salmon-white testa.

More than 100 crosses were made with objectives related to maturity, seed size and seed color.

Crossing technique. The small chickpea flower, about 1-cm in length, has five sepals, five petals, ten diadelphous stamens and one pistil. Emasculation for crossing requires that we open the bud and remove the stamens which is an intricate task (Figure 12). This year we investigated several variables dealing with emasculation and pollination.

Time of Day. We gathered data on seed set related to pollination during different time periods. Data recorded in Table 11 suggest that under our conditions, pollination can be done at any time of day between 0800 and 1700 hours.

Table 12. Seed-Set Percentages According to Simultaneous or Consecutive-Day Emasculation and Pollination, Hyderabad, 1974

Method	Percentage of Seed-Set
Consecutive days (n = 713 flowers)	15.0
Simultaneous (n = 576 flowers)	23.6

Time of Emasculation and Pollination. Practices with chickpea in India have called for emasculation on one day, with pollinating done the next day. In some grain legumes the two procedures are done simultaneously. We experimented with both methods. Table 12 shows that the simultaneous method gave better results.

Other Breeding Variables. We recorded and analyzed several other factors related to our success in the mechanics of breeding this self-pollinated crop. Our overall success average was 13.3%, with seeds produced by 10,114 of the 76,059 flowers emasculated and pollinated. Among 20 persons who made crosses, the individual success rates ranged from 5% to 50%.

In summary, observations concerning crossing techniques disclosed variations (1) person-to-person, (2) cross-to-cross, (3) by stage of plant growth, (4) temperature, (5) humidity, and (6) whether by simultaneous or consecutive-day emasculation and pollination.

Figure 11. Variation in seeds per pod in ICRISAT chickpea germplasm.

CLOSELY RELATED INVESTIGATIONS

Entomology

Only the gram pod borer (*Heliothis armigera* Hb.) caused important insect damage this year. Every culture among the 4,709 chickpea lines sustained some damage from this insect. We considered 60 lines as "severely damaged", having 45% or more of their pods damaged.

We were able to get good control of the gram pod borer with Dimecron (0.05%) and Thiodan (0.07%), the two chemicals we tried this year.

Pathology

Wilt, blight (*Ascochyta rabiei*), foot rot (*Operculella padwicki*), stem rot (*Sclerotium rolfsii* and *Sclerotinia sclerotiorum*), and rust (*Uromyces* sp.) are the principal diseases that may damage chickpea. Wilt is the most serious in India, causing as much as 15% loss in yield; wilt also is significant in other chickpea regions.

In 1974 we made preparations for pathological investigations in subsequent years. Wilt pathogens were collected from six areas of India--Jabalpur, Badnapur, Kanpur, New Delhi, Ludhiana and Hissar. We will select the virulent pathogens among this collection and use them for creating a wilt-sick plot where we can screen for wilt-resistance among the germplasm resources.

LOOKING AHEAD IN CHICKPEA IMPROVEMENT

Off-season nursery. The agro-climatic conditions at Hyderabad limit us to a single chickpea crop each year. But we can use other locations to reduce the time required to move from crosses to releasable material. In 1974 we established an off-season nursery at Kferdan, in Lebanon. The nursery includes 423 F_1 crosses made at Hyderabad this year. We also have a crossing block nursery plus material for a heterosis study and yield trials.

Figure 12. ICRISAT Pulse Breeder Dr. K.B. Singh works on crossing techniques for chickpea.

A similar planting at Lahaul Valley in North India will add to our supply of F_2 seeds for 1974–75. The Hyderabad planting in October will contain seeds from the 500 single and multiple crosses from off-season nurseries.

Fertilizer and water response. Varieties that respond to fertilizers and irrigation would be useful for areas that are seasonally dry through much of the chickpea's growth. Segregating populations with additions of 25-kg of nitrogen and 80-kg of phosphoric acid per ha will be grown with two irrigations. Once synthesized, these lines will be tested under high, normal and low fertility and under both irrigated and rainfed-only conditions.

Breeding material. ICRISAT is working to generate breeding material as rapidly as possible. We have tentative plans to supply material for a crossing block nursery and F_2 bulk populations in 1975; for a screening nursery of F_5 generations in 1976; and material for elite trials in 1977. These will be available to chickpea breeders throughout the semi-arid tropics.

Entomology. In entomological studies, we will investigate the biology, nature of damage and alternate hosts of the insects that damage chickpea Also, insecticides and application rates that will give effective control must be found. Resistance to insects, especially the gram pod borer, will be part of the observations of germplasm and segregating populations. Development of an artificial medium for the pod borer will permit us to develop a population that could be used in controlled trials.

Disease resistance. The wilt-sick plot for screening germplasm for resistance will be a major concern immediately. We will screen for resistance to other important chickpea diseases. Feasible and economical control techniques for chickpea diseases—either chemical or biological—will be explored.

PIGEONPEA IMPROVEMENT

GERMPLASM

Our 1973 plantings of pigeonpea included 2,940 cultures. They originated from such scattered locations as Puerto Rico, Trinidad, Brazil, United States, Nigeria and many locations in India. During the year 499 others were obtained, bringing our total accessions to 3,439.

We recorded several observations of the cultures planted in 1973 (Figure 13). Table 13 subdivides the germplasm by maturity groups and by seed size. These following ranges give some indication of the diversity among the lines:

- Time from planting to floral initiation: 54 to 238 days.
- Plant height at 50% flowering: 83 to 302-cm. Width of plant at same stage: 15 to 172-cm.
- Number of branches: 2 to 42..
- Number of seeds per pod: 2 to 6.
- 100-seed weight: 4.7 to 19.5-grams.

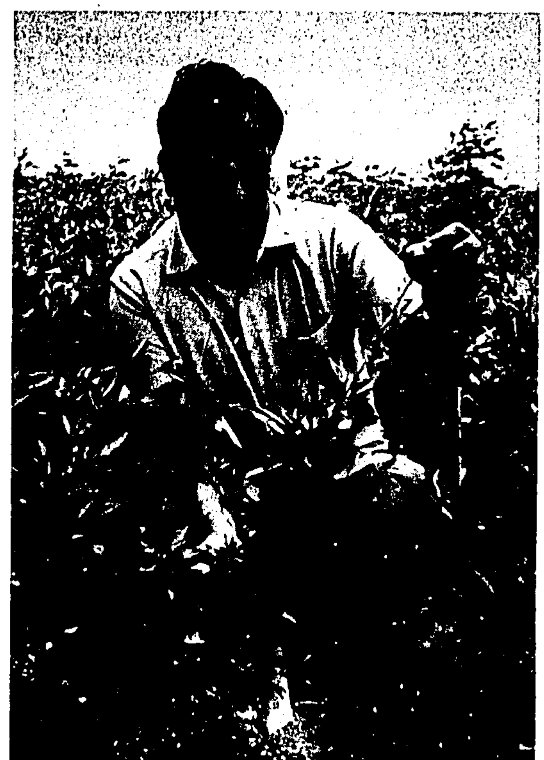


Figure 13. ICRISAT Pulse Breeder Dr. D. Sharma makes observations of 1973 cultures.

Survey and Collection

Some authorities place the origin of pigeonpea in Africa, while some present evidence suggests India—where 90 percent of current pigeonpea area is found. Whether the center of origin or not, India offers a rich source for survey and collection of genetic

Table 13. Pigeonpea Germplasm Accessions—Classified by Maturity, Plant Type and Seed Size, Hyderabad, 1973–74

Plant Type	Maturity—Seed Size								
	Early Maturing			Medium Maturing			Late Maturing		
	Small	Medium	Bold	Small	Medium	Bold	Small	Medium	Bold
TALL									
Spreading				150	1		105	1	
Semi-spreading				376	3	2	226	4	1
Compact				2			21	5	
MEDIUM									
Spreading	4			586	14		373	2	
Semi-spreading	10			544	4	2	387	4	3
Compact				10			34	2	
DWARF									
Spreading				8	1		6		
Semi-spreading	1			32	4		9		
Compact	1				1		1		
TOTAL	16			1,708	28	4	1,162	18	4

Total classified	2,940
Not classified	499
TOTAL GERMPLASM	3,439

materials. The state of Madhya Pradesh has some characteristics to recommend it as a source for the plant breeder: Pigeonpea is grown there under different cropping systems in diverse eco-geographical areas; there has been little movement of seed from one place to another, tending to preserve local types.

Our main collections in India were taken in Madhya Pradesh, with some lesser attention in bordering areas of Andhra Pradesh, Orissa, Uttar Pradesh and Maharashtra.

We collected 134 samples of pigeonpea, taking seeds from farmers' fields and from village markets. Types range from tall and compact with few branches to dwarf and semi-tall with spreading branches. Some are bushy types with many secondary branches. Weights range from 5.4 to 20.7-grams per 100 seeds.

In these survey trips we saw pigeonpea growing under diverse field conditions, on soils ranging from very light, stony red types to loam and heavy clay soils. Pigeonpeas are grown with millets, sorghum, groundnut, castor, chillies, cotton and a variety of other crops.

Three especially interesting specimens from these collections are:

- A perennial pigeonpea, found growing almost as a tree in the kitchen garden of a farm family in a remote area of Bastar District in Madhya Pradesh. The plant produces very bold white seeds, which are eaten as green peas.

- A medium maturing type with very bold, dark brown seeds, collected near Jabalpur. It is the boldest seed type in our collection with 100-seed weight of 20.7-grams.
- A 4-foot semi-compact plant with indeterminate growth habit. The seed is pearly white and medium bold, and the plant has a high harvest index. It was collected from the village of Badalkhedi in the Malwa region of Madhya Pradesh.

APPLIED BREEDING PROGRAM

Early maturing varieties. One of the major limitations on adaptation of pigeonpea to wider use in the semi-arid tropics is the long-season nature of most varieties. Early maturing varieties would make it possible to fit this pulse into several additional cropping systems. They would also perform better on soils that have lower water-holding capacity. They would be adapted to areas with frost, which is one of the main factors limiting pigeonpea production in India.

However, present early maturing varieties have small grain size, which does not meet the consumer's demand in pigeonpea.

First steps were taken this year in an effort to obtain bold-seeded, early maturing varieties. We chose 17 bold-seeded types: 5 types from Bastar in Madhya Pradesh and 12 exotics, mostly from Puerto Rico. These were crossed with T-21 and Pusa Ageti, standard small-seeded, early maturing types.

High yielding varieties. In rainfed areas of India, pigeonpea is mainly grown as a dry season, rabi, crop. It utilizes residual moisture. Relatively low yields, however, relegate it to low priority with most farmers. Suitable high yielding varieties could earn pigeonpea a more prominent place as a competitive cash crop. We began hybridization toward types with bold seeds and superior yield ability. The germplasm in the medium maturity range appears to have the most promising variability for yield components—number of primary and secondary branches, number of seeds per pod and 100-seed weight (Figure 14). From that group we chose three of the most promising current varieties: Sharda, NP-69 and Gwalior 3-191-1. They were crossed with five very bold-seeded Bastar types, JA-274 through JA-278.

Extent of cross-pollination. Pigeonpea is a self-pollinated crop, but some cross-pollination occurs. The literature reports wide differences in the extent of cross-pollination. As high as 65% cross-pollination has been reported, although 15 to 20% is generally considered a more typical level. Critical observations from Puerto Rico, however, indicate only 6%.

A breeding program requires precise information on the extent of crossing. Two cultures among our germplasm will permit us to initiate study of this problem. These cultures have a characteristic obtuse leaf apex governed by a single recessive gene.

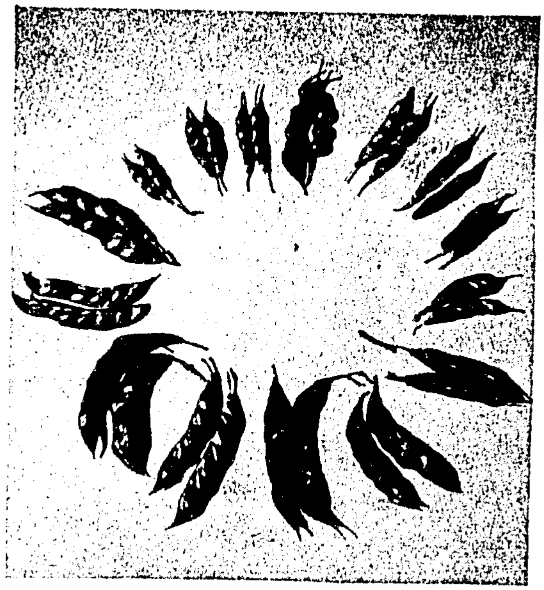


Figure 14. Pigeonpea exhibits a wide variation in number of seeds per pod and 100 seed weight.

We will plant the harvested seeds of these cultures. The frequency of normal-leaf plants in the progeny will indicate extent of outcrossing. Additional information on between-row crossing will be obtained from white-seeded cultures.

Off-season nursery. Farmers normally grow and harvest only one crop of pigeonpea per year in the Hyderabad area. We are eager to reduce the time between crossing and "proving" genetic material by growing more than a single generation each year.

Pigeonpea is considered relatively photoperiod-sensitive, so we are trying it in year-around plantings. We chose ten varieties that represent different maturity groups for the trial. A first planting was made 31 Jan. 1974, a second on Feb. 15 and a third on Mar. 21. Plantings will be made each month for the year.

Among our preliminary observations:

- Crop growth was good, but plant stature was less than expected in main season growth; there was little height difference between the January and February plantings.
- There was little difference in dates of 50% flowering between February and January plantings; early maturing types began to bloom in 71 days; medium duration types had not initiated flowers after 90 days.
- It is doubtful that we could make selections in the breeding programs from these off-season plantings, but it may be possible to advance a generation by growing early maturing and some medium maturing types from plantings in late December to early January.

CLOSELY RELATED INVESTIGATIONS

Entomology

Pod borers. Pod borers rank as the principal insect pest of pigeonpeas in India. This hazard is one reason that pigeonpeas are not more widely grown. Our pigeonpeas did not escape; pod borers damaged an estimated 60 to 100% of pods in our germplasm cultures (Figures 15 and 16). Two lines had comparatively less damage: Sharda and culture No. 1861.

We identified five species that damaged pigeonpea pods: tur pod borer (*Heliothis armigera* Hb.), pod fly (*Melanagromyza obtusa* M.), plume moth (*Exelastes atomosa* W.) and two Lycaenid butterflies (*Lampides boeticus* L. and *Catochrysops cnejus* F.)

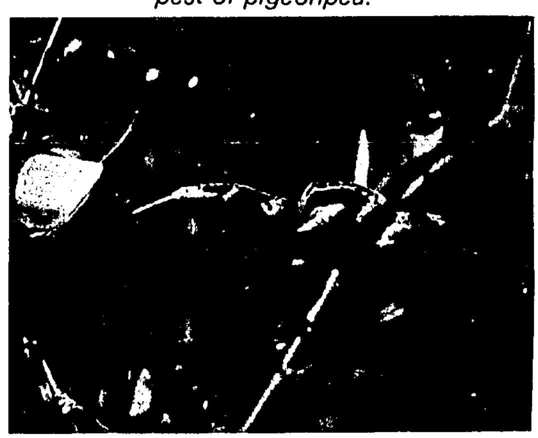
We tested three insecticides against the borers during the growing season, Endrin 20 ec, Ambithion 500 E and Thiodan 35 ec. Thiodan 35 ec sprayed every seven days gave effective control.

Other insects. Seven other insects were identified in our pigeonpeas. Four sucked sap from leaves, flowers and pods—*Clavigrella horrens* D., *Clavigrella gibbosa* S., *Riptortus pedestris* F. and *Nezara viridula* L. The blister beetle, *Mylabris pustulata* T., damaged flowers and flower buds; thrips were also common on flowers. We observed the pulse beetle, *Bruchus* sp., feeding on developed grains at harvest.

Pathology

We found five disease pathogens in the 1973–74 pigeonpea plantings. None was either widespread or seriously damaging.

Figure 15. Pod borers: the principal insect pest of pigeonpea.



Wilt. Wilt symptoms appeared after rains in mature plants in four of the 2,940 lines. Plants wilted suddenly, as if from water shortage, although there was plenty of moisture available. After the wilting, leaves yellowed, withered and dried; roots and stem base blackened. The lines affected were P-396, P-400, P-431 and P-507.

We isolated the pathogen, *Fusarium oxysporum* f. *udum* (Butler) for further study. We also collected wilted plants from Kanpur, Delhi and Badnapur to study variability of the pathogen.

New stem rot. New stem rot caused by *Phytophthora drechsleri* var. *cajani* appeared in low frequency in the off-season nursery. Some yellow mosaic virus also occurred in that nursery.

New stem rot of Arhar. New stem rot of Arhar appeared in month-old plantings when temperatures were in the 36 to 40°C range. The wilting of plants resembled fusarial wilt. The roots appeared to be healthy, but a girdling of the stem developed at or a little above ground level. When the bark was removed we found rotting and discoloration of the woody portion of the stem. The pathogen was *Phytophthora* sp., which we isolated on potato dextrose agar medium, so we can look into its pathogenicity.

Sterility virus infected two plants in the 3-ha plantings of pigeonpeas.

LOOKING AHEAD IN PIGEONPEA IMPROVEMENT

Germplasm. We need to bring to our germplasm collection all the diversity that is to be found. As the world center for pigeonpea germplasm, ICRISAT must survey and collect. We anticipate surveys in two continents considered as possible centers of origin—the center of origin has not been decided conclusively.

We plan to survey the western ghats and Malabar coast of India. A great number of species of *Atylosia* occur in these localities;

Figure 16. Pod borers may damage 60 to 100% of pigeonpea pods.

Atylosia is believed to be a progenitor of *Cajanus*. Another expedition in India will survey Assam, which represents a different agro-climatic region.

Several areas in Africa should prove to be rich sources of diverse germplasm. Pigeonpea was found growing wild in the upper Nile region, coastal districts of Angola, and from Zanzibar to the coast of Guinea. Other wild types have been observed in China, Vietnam, Laos, Cambodia, and on Central Java's Mageland mountains.

We will grow out the entire germplasm collection grouped on bases of maturity, growth habit and stature. The lines will be purified by removing types with undesirable morphological characteristics, and on the basis of seed color.

Yield potential will be evaluated in our plots of three 5-meter rows with a check entry with each group.

Pathologists will evaluate the germplasm for resistance to wilt and new stalk rot. Entomologists will study differential reactions to insect enemies.

Breeding. As staff resources increase, the hybridization program will be intensified. We plan an extensive series of diallel crosses involving different maturity groups, plant types and seed size. Seed size of parents in the diallel crosses will range from 7 to 20.7-grams per 100 seeds. By comparing performance of crosses to the parents, we can identify desirable combinations for further intensive work.

ICRISAT plant breeders and entomologists will cooperate to obtain data on insect vectors in cross-pollination. We will study natural crossing in more detail using certain gene markers that are available in our collection.

Exploration within India and internationally for off-season nursery sites will receive a high priority. Pigeonpeas planted in different seasons in Hyderabad displayed wide growth variation. Monthly plantings at three latitudes in India may help to determine the effect of season and locations on the growth pattern of pigeonpea. The locations chosen are:

Udaipur, Rewa	C 24°N
Mahabaleshwar, Hyderabad	C 17°N
Ootacamund, Coimbatore	C 11°N

We will also explore possibilities for plantings in Queensland, Australia, Northeast Brazil, and similar latitudes.

Entomology and pathology. Our entomologists have identified blocks of information needed for understanding the relationship of insects to pigeonpeas. This has not been studied systematically. We expect to undertake a variety of entomological studies:

- Probing the biology of the insect pests that affect pigeonpeas, examining the nature of damage and exploring biological control.
- Determining incidence and periodicity of insect pests.
- Estimating yield losses in certain varieties due to different pod borers.
- Finding plant protection means and schedules, utilizing available, safe and inexpensive insecticides.
- Studying the effects on incidence of insect pests when pigeonpeas are grown in mixture with cowpeas, soybean, sorghum and pearl millet.

Pathologists have collected wilt pathogens to produce a wilt-sick plot. There we can study the effect of the disease under controlled infection and we can screen lines for reaction. We will do similar work with the new stem rot under artificial epiphytotic conditions.

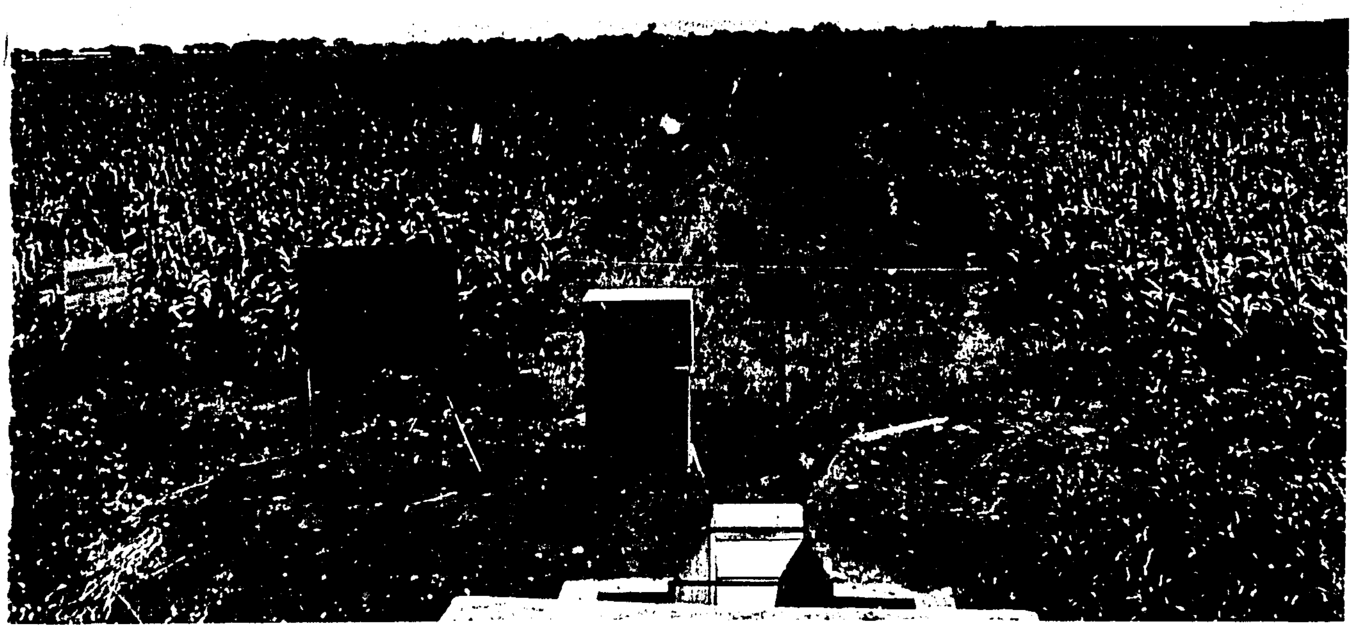
PART 2. FARMING SYSTEMS

RESEARCH ON PRODUCTION FACTORS

Fertilizer Trials and Intercropping are two areas of production factor research. This phase of the Farming Systems Program focuses on many interrelated components of crop production.

RESOURCE MANAGEMENT

A "developed" watershed at ICRISAT. The watershed has been selected as a realistic scale model for resource management investigations.



FARMING SYSTEMS

INTRODUCTION

Our goals in ICRISAT—from the beginning—have embraced better systems of farming as well as better genetic materials for the semi-arid tropics. The farming systems goal has two dimensions: (1) increasing agricultural output in the semi-arid tropics and (2) making it more stable season-to-season and year-to-year.

We must deal with various centuries-old constraints to make progress toward these goals. Some constraints are educational, social, economic and personal; others are technological. It is on these technological constraints that we place our early attention.

Dual approach. The first two years of farming systems research has concentrated on two areas of investigation. One deals with resource management, exemplified in innovations we are testing in small-watershed systems. The other area deals with research on production factors—tillage, planting methods, intercropping, relay cropping, supplemental irrigation, fertilization and the development of improved animal-drawn implements.

This section of our report divides along these two lines. While the two areas of study are closely related, we have separated them to report. First, we take up two years of research results on production factors. Second, we have detailed the basic approach and first-year results of studies of the concepts involved in the small-watershed approach to soil and water management.

FARMING SYSTEMS RESEARCH ON PRODUCTION FACTORS

Practices we are investigating among production factors are not new to the agriculture of India. Some are not widely known or practiced, such as the ridge-and-furrow system. Some have not been through disciplined testing of science under controlled conditions such as those maintained at ICRISAT.

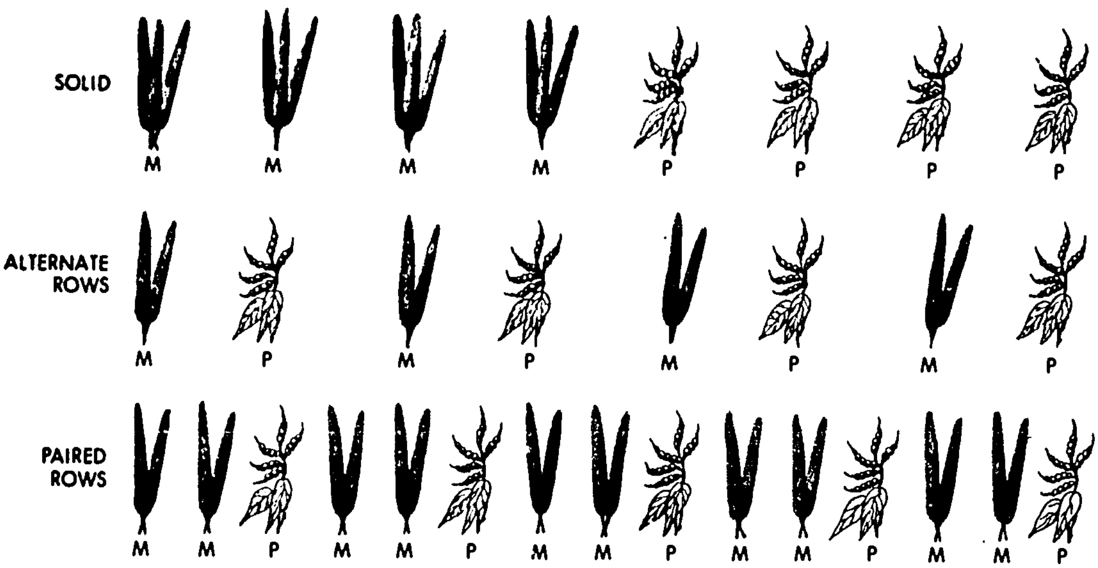
As we seek improved production systems, we look into many potentially productive ideas. We build on the work of others. For example, consultations and review of reports from many talented researchers in India have contributed much to our program. As our international outreach and training efforts build more bridges, we expect an increasing interchange among all who seek to improve farming throughout the world's semi-arid tropics.

INTERCROPPING

Purpose of Study

The climate at ICRISAT permits two distinct crop seasons—the monsoon or kharif season, typically from June through early October, and the dry or rabi season, October to the onset of summer in February. However, with indigenous tools and power, ground preparation to plant in the rabi season is often difficult and sometimes impossible.

Figure 17. Row Layout for Methods of Planting in Intercropping Experiments.



P indicates row in pigeonpea.
M refers to millet.

Row Spacing: Solid, 45-cm
Alternate, 45-cm
Paired, 22.5-cm

In trials with other crops, the companion was planted where pearl millet is shown in this illustration.

Pigeonpea, a slow-starting plant, offers one kind of solution to that problem. It can be grown as an intercrop, planted at the same time as the kharif crop and left to make its main growth and production after the associated kharif crop is harvested in September or early October. We are also examining the moisture conservation effects of this system.

Description of Experiment

Last year's investigations at ICRISAT involved a comparison of solid planting and intercropping in alternate rows. This year we expanded with a third configuration of planting, doubling coverage of the land and giving higher populations per area of both crops. Figure 17 illustrates the three planting systems studied this year. The situation we call "paired rows" provides one-third more rows of pigeonpea and increases the number of rows of the companion crop by 2–2/3 times.

One set of intercropping experiments used pigeonpea with, respectively, mungbean, soybean, finger millet and sunflower (Figure 18). We carried out these experiments on both red soil and black soil. However, sandblast injury to pigeonpea in the sunflower plot on red soil—due to its location—was so severe that we dropped it from the trial.

Results

Table 14 reports the yield results from intercrop trials on red soils. In all cases, the paired rows method produced significantly higher pigeonpea yields and also

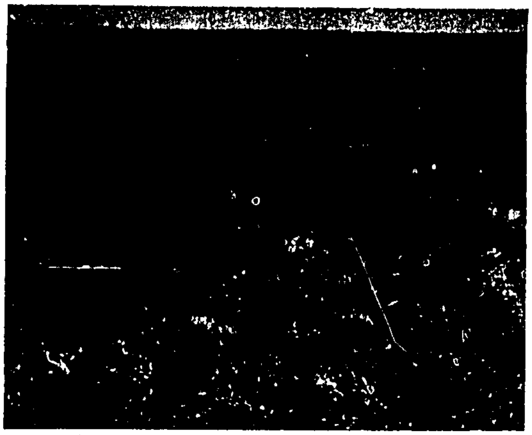


Figure 18. Intercropping experiments at ICRISAT.

significantly higher yields of the three companion crops; i.e., mungbean, soybean and finger millet.

In the soybean-pigeonpea combination, alternate row plantings produced significantly more than solid. Finger millet planted in alternate rows in combination with pigeonpea was significantly better than solid planting, although the associated pigeonpeas did not produce the same superior result.

Black soil trials showed comparable results (Table 15). In all cases the paired rows treatment produced significantly more pigeonpea and more of the companion—mungbean, soybean, finger millet and sunflower. Finger millet was the only crop to produce significantly higher in alternate-row planting than in solid planting.

Table 14. Yields of Three Intercrop Combinations by Method of Intercropping with Pigeonpea on Red Soil, Hyderabad, 1973

Intercrop	Method of Cropping			
	Solid q/ha	Alternate Rows q/ha	Paired Rows q/ha	LSD (05) q/ha
Mungbean-Pigeonpea				
Mungbean	2.1	2.3	4.0	0.9
Pigeonpea	9.0	11.0	16.7	2.1
Soybean-Pigeonpea				
Soybean	3.4	3.7	6.7	0.3
Pigeonpea	7.8	14.4	19.8	3.7
Finger Millet-Pigeonpea				
Finger Millet	10.1	16.4	24.6	5.2
Pigeonpea	5.1	5.5	8.5	1.5

For intercropping pattern, see Fig. 17.

Harvest dates : Mungbean: Aug. 27. Soybean: Oct. 20. Finger Millet: Oct. 15. Pigeonpea: Nov. 28.

Fertilizer treatment: All crops received 205-kg/ha of 28–28–0 at planting or a total of 57-kg of nitrogen and 25-kg of phosphorus.

Note : Experiment also included sunflower-pigeonpea system, but sandblast injury to pigeonpea was so severe that yields were not included in the analysis.

Table 15. Yields of Four Intercrop Combinations by Method of Intercropping with Pigeonpea on Black Soil, Hyderabad, 1973

Intercrop	Method of Cropping: Solid q/ha	Alternate Rows q/ha	Paired Rows q/ha	LSD (05) q/ha
Mungbean-Pigeonpea				
Mungbean	1.7	1.8	2.7	0.4
Pigeonpea	3.8	4.4	6.8	1.1
Soybean-Pigeonpea				
Soybean	3.9	4.8	7.6	2.1
Pigeonpea	3.9	4.9	6.5	1.2
Finger Millet-Pigeonpea				
Finger Millet	15.4	17.3	26.1	1.9
Pigeonpea	3.9	4.9	8.2	1.1
Sunflower-Pigeonpea				
Sunflower	10.1	11.9	23.1	1.9
Pigeonpea	2.5	3.0	4.7	1.6

For intercropping pattern, see Fig. 17.

Harvest dates : Mungbean: Aug. 27. Soybean: Oct. 10. Sunflower: Oct. 19. Finger Millet: Oct. 20. Pigeonpea: Nov. 30.

Fertilizer treatment: All crops received 205-kg/ha of 28–28–0 at planting or a total of 57-kg of nitrogen and 25-kg of phosphorus.

Pearl millet-pigeonpea intercropping. We used the same planting systems in two intercropping trials with pigeonpea and pearl millet. In these trials the pearl millet was ratooned. A harvest sequence of fodder-fodder-grain and stalk was carried out in one experiment on both red and black soils. Paired rows yielded significantly higher than alternate rows or solid plantings in all cases (except on the black soil trial where the dry stalk differences were not significant). In no case was the yield of pearl millet grown in alternate rows significantly higher than from the solid planting. Pigeonpeas on both soils recorded significantly higher yield in alternate rows than in solid plantings. Tables 16 and 17 record the data of those trials.

Intercropping plus ratooning. Our pearl millet-pigeonpea intercropping investigation also included other systems of ratooning the pearl millet. Four harvest sequences were: GF, harvest of grain and stalk plus a later green fodder crop; FG, harvest of green fodder followed by a later grain and stalk crop; FFG, two green fodder crops followed by a grain and stalk crop; FFF, three green fodder crops.

The average pigeonpea yield of the four harvest systems was significantly better in alternate rows than for solid planting, and paired rows yielded significantly higher than both other planting systems. With pearl millet forage, both alternate rows and paired rows were generally significantly higher

Table 16. Yields of Pigeonpea and Pearl Millet Intercropped by Three Planting Systems on Red Soil, Hyderabad, 1973

Crop	Method of Planting			
	Solid q/ha	Alternate Rows q/ha	Paired Rows q/ha	LSD (05) q/ha
Pigeonpea	8.8	10.6	13.5	1.0
Pearl Millet Ratooned FFG				
Green fodder	129.9	183.3	291.6	66.7
Green fodder	70.8	75.7	140.3	27.8
Grain	4.5	5.1	8.3	1.4
Stalk—dry	9.0	9.6	15.6	1.3

For intercropping pattern, see Fig. 17.

Harvest dates : Pearl millet—green fodder: Aug. 9 and 30—grain and stalk: Oct. 20. Pigeonpea: Nov. 27

Varieties : Pearl millet, J1270; pigeonpea, Pusa Ageti.

Fertilizer treatments: 205-kg/ha of 28–28–0 at planting plus 43-kg/ha of nitrogen at first harvest or a total of 100-kg of nitrogen and 25-kg of phosphorus.

Table 17. Yields of Pigeonpea and Pearl Millet Intercropped by Three Planting Systems on Black Soil, Hyderabad,1973

Crop	Method of Planting			
	Solid q/ha	Alternate Rows q/ha	Paired Rows q/ha	LSD q/ha
Pigeonpea	2.3	3.1	5.4	0.7
Pearl Millet Ratooned FFG				
Green fodder	122.7	137.2	221.3	23.3
Green fodder	61.1	68.2	110.4	13.3
Grain	2.4	2.5	4.0	0.2
Stalk—dry	9.0	10.3	15.2	NS

For intercropping pattern, see Fig. 17.

Harvest dates : Pearl millet—green fodder: Aug. 20 and Sept. 3—grain and stalk: Oct. 19. Pigeonpea: Nov. 30.

Varieties : Pearl millet, J1270; pigeonpea, Pusa Ageti.

Fertilizer treatments: 205-kg/ha of 28–28–0 at planting plus 43-kg/ha of nitrogen at first harvest or a total of 100-kg of nitrogen and 25-kg of phosphorus.

than solid, with paired rows significantly higher than alternate rows. Paired rows of pearl millet also yielded significantly more grain than did other configurations regardless of when grain harvest came in the ratooning sequence. Table 18 reports the data in full.

RELAY CROPPING

Purpose of Study

Relay cropping is another practice designed to use the second season in the semi-arid tropics. It helps overcome post-monsoon land preparation problems, takes advantage of late-monsoon rains to aid establishment, and makes efficient use of residual moisture left after the kharif crop. The term "relay" connotes the practice of planting the second crop before the kharif crop has been harvested.

Description of Experiment

We undertook trials to explore the effect of planting time with relay crops (Figure 19).

Table 18. Yields of Ratooned Pearl Millet and Pigeonpea Intercropped by Three Planting Systems on Black Soil, Hyderabad, 1973

Harvest system / Planting system	Yields-q/ha										
	AUGUST	SEPTEMBER			OCTOBER			NOVEMBER			
	Fodder	Fodder	Grain	Stalk	Fodder	Grain	Stalk	Fodder	Grain	Stalk	Pigeonpea
GRAIN-FODDER											
Solid			14.3	28.1	14.4						4.0
Alternate			16.9	32.2	15.4						6.0
Paired rows			27.8	49.8	29.2						7.7
LSD (05)			5.0	11.1	6.5						
FODDER-GRAIN											
Solid	65.8					5.1	4.9				4.1
Alternate	101.7					5.6	5.6				5.9
Paired rows	151.3					8.2	8.7				8.3
LSD (05)	27.8					0.7	1.5				
FODDER-FODDER-GRAIN											
Solid	65.8	27.9							1.8	6.6	4.9
Alternate	101.7	39.4							2.0	6.9	6.5
Paired rows	15.3	66.1							4.1	10.1	10.0
LSD (05)	27.8	9.8							1.0	NS	
FODDER-FODDER-FODDER											
Solid	65.8	27.9						11.6			3.9
Alternate	101.7	39.4						17.2			7.3
Paired rows	151.3	66.1						28.8			9.9
LSD (05)	27.8	9.8						11.8			

For intercropping pattern, see Fig. 17

Varieties : Pearl millet, HB-3; pigeonpea, Pusa Ageti.

Fertilizer treatments : 205-kg/ha of 28–28–0 at planting plus 43-kg/ha of nitrogen at first harvest or a total of 100-kg of nitrogen and 25-kg of phosphorus.

Figure 19. ICRISAT Farming Systems Scientist Dr. B.A. Krantz examines kharif crop in relay planting trial.

Safflower and chickpea were chosen to follow kharif sorghum. Three planting times were selected: two weeks before expected sorghum harvest; one week before sorghum harvest; and immediately after sorghum harvest.

Results

Time of planting relative to sorghum harvest had little effect on safflower or chickpea yield (Table 19). Actually the effective date of planting varied slightly for the two treatments planted before sorghum harvest: The earlier planting was made in dry soil; the second planting was made at the time of rain, which led to germination of both plantings.

Moisture Utilization

One interest in this study also related to utilization of moisture. We planned three water "treatments" as part of this experiment: One planting was put on soil that had been "fallowed" during the preceding monsoon; two series of plantings were placed where kharif sorghum crops had been grown. One of the latter two series received 5-cm of

Table 19. Effect of Time of Planting on Yields of Relay Crops of Safflower and Chickpea, Hyderabad, 1974

Time of Planting Relative to Sorghum Harvest	Relay Crops	
	Safflower q/ha	Chickpea q/ha
Red Soil		
Two weeks before	12.0	4.1
One week before	11.0	5.3
Immediately after	11.3	4.3
LSD (05)	NS	0.7
Black Soil		
Two weeks before	14.2	9.6
One week before	14.0	9.4
Immediately after	13.1	8.9
LSD (05)	NS	NS

Varieties : Safflower, S-11; chickpea, BEG-482. Fertilization : Uniform and adequate.

Table 20. Effect of Three Moisture Conditions on Yields of Relay Rabi Crops for Safflower and Chickpea, Hyderabad, 1974

Moisture Condition	Relay Crops	
	Safflower	Chickpea
	q/ha	q/ha
Red Soil		
Following sorghum	10.8	3.9
Following sorghum—5-cm irrigation	12.4	5.8
Following fallow	11.0	3.8
LSD (05)	0.7	1.0
Black Soil		
Following sorghum	12.8	8.6
Following sorghum—5-cm irrigation	12.7	10.8
Following fallow	15.1	8.2
LSD (05)	NS	NS

Varieties : Safflower, S-11; chickpea, BEG-482. Fertilization : Uniform and adequate.
Irrigation : 5-cm applied on Nov. 26.

supplemental irrigation applied to the relay crops.

Results. Table 20 gives the results of the two experiments. On the red soils of the ICRISAT site, moisture conditions of the relay crops were significantly related to yields. A 5-cm supplemental irrigation produced significantly higher yields in both safflower and chickpea.

Monsoon fallowing. Perhaps the most important observation from these data concerns the level of yields from rabi crops grown on soil fallowed during the monsoon. In no case was the measured yield from the fallowed treatment significantly different than the unirrigated crop following the kharif sorghum. However, this year late rains in September and October may have helped to narrow differences. Results for a comparatively drier or normal year remain to be recorded.

On an input-output basis, the fallowing system produced less or no more than relay crops grown after, respectively, 41.6 and 34.0-q/ha of sorghum grain crops in kharif

On the input side, the fallow treatment also included the cost of several tillage operations to check weeds during kharif; and the land without vegetative growth during the rainy season was also more vulnerable to erosion. Thus the economics of kharif fallowing is highly questionable.

Under conditions of the 1973–74 crop season, relay cropping provided resource utilization much superior to kharif-only and to fallow-and-rabi cropping with the three crops grown in this trial.

PEARL MILLET RATOONING

Purpose of Study

Pearl millet tillers profusely. When part of the plant is removed during the growing season, other tillers shoot upward. This characteristic permits the practice of ratooning. Numerous harvests can be taken from the same plants permitting savings in tillage operations and increased water use efficiency.

Farmers and agriculturists greeted the

ratooning experiments in the first crop year at ICRISAT with great interest. We responded to this interest by planning an expanded series of ratooning experiments for 1973.

Description of Experiment

We experimented with a variety of harvest patterns (Figure 20). A grain crop can be followed with green fodder crops. More than one grain crop can be harvested; or as many as five green fodder crops can be harvested.

Our 1973 trials dealt with possible differences in ratoonability of four leading Indian pearl millet varieties: HB-3 and HB-4 grown on red and on black soil, K559 on black soil; and J 1644 on red soil.

Results

Tables 21 and 22 report our results. Table 21 shows varietal yield differences reached statistically significant levels to a greater extent on black soil than on red soil. No single varietal superiority was evident, however. In many cases both HB-3 and HB-4 were significantly higher yielding than K559. More trials should be carried out before any recommendation is advanced on relative ratoonability of pearl millet varieties.

Figure 20. Pearl millet ratooning: a possible drought insurance.

Table 22 shows three pearl millet varieties ratooned on red soils differed significantly in several treatments. However, little can be concluded from the scattered pattern of differences. No variety showed a consistent ability to yield better than others.

Table 23 summarizes production of grain, stalk and/or green fodder for each of six harvest systems observed. Data are given as means of the three varieties included in these trials. In addition to total production under each system, the date on which the land was again available for another use is also noted.

Conclusions

We are uncertain as to the practicality of the systems that maximize green fodder production. Silage would seem a logical way that extra forage produced during kharif could be stored for rabi season use. Yet it is not a well-established practice in the semi-arid tropics. In a normal kharif season, the time of maximum pearl millet forage growth comes when other forages are also at their best and generally sufficient to meet the grazing needs of livestock—at least in the Hyderabad area.

In the continuing drought of the 1972 crop season, the need for green forage was more acute. Then, pearl millet offered a useful and abundant source of such forage.

Perhaps the ratoonability of pearl millet adds a degree of versatility that could be useful in a period of unfavorably dry monsoon.

METHOD OF PLANTING

Purpose of Study

Two principal soils of the semi-arid tropics are the black and red soils. They differ in many characteristics; among them, in ability to absorb and retain rainfall moisture. The higher clay content of black soils permits slower infiltration of rainfall, with subsequent potentially erosive runoff or

Table 21. Yields of Three Pearl Millet Varieties Under Six Systems of Ratoon Harvesting on Black Soil, Hyderabad, 1973

Harvest System / Variety	Yields-q/ha										
	AUGUST		SEPTEMBER			OCTOBER			NOVEMBER		
	Fodder	Fodder	Grain	Stalk	Fodder	Grain	Stalk	Fodder	Grain	Stalk	Fodder
GRAIN-GRAIN											
HB-3			25.6	64 9					9.0	13.2	
HB-4			29.2	67.5					10.7	15.2	
K559			22.0	69.0					10.0	17.3	
LSD (05)			3.4	NS					NS	NS	
GRAIN-FODDER-FODDER											
HB-3			25.6	64.9				16.3			7.9
HB-4			29.2	67.5				5.1			2.7
K559			22.0	69.0				10.1			4.2
LSD (05)			3.4	NS				4.1			2.2
FODDER-GRAIN											
HB-3	174					21.7	38.3				
HB-4	182					15.0	40.5				
K559	153					17.5	41.4				
LSD (05)	16.7					3.1	NS				
FODDER-FODDER-GRAIN											
HB-3	174	124				5.4	9.1				
HB-4	182	141				6.2	9.4				
K559	153	118				6.5	10.4				
LSD (05)	16.7	8.8				NS	1.1				
FODDER-FODDER-FODDER-GRAIN											
HB-3	174	124			44.5				4.6	8.5	
HB-4	182	141			51.6				5.0	9.9	
K559	153	118			39.5				5.7	11.4	
LSD (05)	16.7	8.8			3.8				0.6	NS	
FODDER-FODDER-FODDER-FODDER-FODDER											
HB-3	174	124			44.5			39.7			16.4
HB-4	182	141			51.6			34.8			15.7
K559	153	118			39.5			37.5			15.6
LSD (05)	16.7	8.8			3.8			2.5			NS

Fertilization : Uniform and adequate
Yields reported in month of harvest.

Table 22. Yields of Three Pearl Millet Varieties Under Six Systems of Ratoon Harvesting on Red Soil, Hyderabad, 1973

Harvest System / Variety	Yields-q/ha										
	AUGUST		SEPTEMBER			OCTOBER			NOVEMBER		
	Fodder	Fodder	Grain	Stalk	Fodder	Grain	Stalk	Fodder	Grain	Stalk	Fodder
GRAIN-GRAIN											
HB-3			27.1	47.7					1.2	2.6	
HB-4			28.4	48.8					1.3	2.5	
J1644			27.8	48.5					1.4	2.8	
LSD (05)			NS	NS					NS	NS	
GRAIN-FODDER-FODDER											
HB-3			27.1	47.7				7.4			6.1
HB-4			28.4	48.8				3.9			6.7
J1644			27.8	48.5				5.3			5.7
LSD (05)			NS	NS				2.4			NS
FODDER-GRAIN											
HB-3	229					12.9	21.4				
HB-4	229					13.7	21.7				
J1644	218					11.7	20.6				
LSD (05)	NS					NS	NS				
FODDER-FODDER-GRAIN											
HB-3	229	136				8.0	11.2				
HB-4	229	141				7.5	9.7				
J1644	218	152				7.7	10.0				
LSD (05)	NS	3.8				NS	NS				
FODDER-FODDER-FODDER-GRAIN											
HB-3	229	136			44.1				1.5	4.1	
HB-4	229	141			50.1				1.4	4.4	
J1644	218	152			41.6				1.4	4.2	
LSD (05)	NS	3.8			4.3				NS	NS	
FODDER-FODDER-FODDER-FODDER-FODDER											
HB-3	229	130			44.1			50.1			3.0
HB-4	229	141			50.1			36.3			1.9
J1644	218	152			41.6			45.6			1.7
LSD (05)	NS	3.8			4.3			7.4			0.7

Fertilization : Uniform and adequate
Yields reported in month of harvest.

standing surface water, depending on topography. The red soils usually take falling rain more rapidly into the profile, but they have a lower water holding capacity than the black soils.

Ridge planting is one method of altering plant environment to deal with potential problems of slow infiltration. Ridges become small "terraces" to intercept rainfall and limit speed and amount of runoff. Also, ridges put the plant and part of its root system several inches higher than the normal flat soil surface. Such plants are less likely to have their entire root system under water.

Description of Experiment

We compared ridge planting and flat planting with four crops grown during kharif 1973: sorghum, pearl millet, sunflower and pigeonpea. Nitrogen fertilizers also entered into this trial, with two levels, 22 and 80-kg/ha of nitrogen.

Results

Table 24 reports yield results for the four crops on the two soils.

Method of planting was not significantly related to yield differences in these trials. Nitrogen fertilization rate accounted for most of the variation measured. Another phenomena was observed in this study: Ridge-planted crops on red soil sustained observably more sandblast damage to seedlings than occurred in the flat plantings. Pigeonpea plant population was 44% greater in flat planting as a result of sandblast, for example.

This experience suggests caution in using ridge-planting at the start of the kharif season in red sandy soils. Where ridges are desired, the planting may be done flat on graded contours with the furrows established by the first cultivation.

Table 23. Yields of Pearl Millet Ratooned Under Six Harvest Systems, Hyderabad, 1973

Harvest System	Yields q/ha			Date of Last Harvest
	Grain	Stalk	Fodder	
Black Soil				
Grain-Grain	36.6	42.3	—	Nov. 8
Grain-Fodder-Fodder	25.6	67.1	15	Nov. 8
Fodder-Grain	18.1	40.1	170	Oct. 18
Fodder-Fodder-Grain	6.0	9.8	297	Oct. 18
Fodder-Fodder-Fodder-Grain	5.1	9.9	343	Nov. 11
Fodder-Fodder-Fodder-Fodder-Fodder	—	—	396	Nov. 8
Red Soil				
Grain-Grain	29.1	50.9	—	Nov. 9
Grain-Fodder-Fodder	27.8	48.3	12	Nov. 11
Fodder-Grain	12.8	21.2	225	Sept. 27
Fodder-Fodder-Fodder	7.7	10.3	368	Oct. 18
Fodder-Fodder-Fodder-Grain	1.4	4.3	414	Nov. 9
Fodder-Fodder-Fodder-Fodder-Fodder	—	—	469	Nov. 11

Based on data presented in Tables 21 and 22.

Table 24. Yields of Four Kharif Crops Under Two Methods of Planting and Two Levels of Nitrogen Fertilization, Hyderabad, 1973

Method of Planting	Nitrogen Level—kg/ha	Crop Yield			
		Sorghum	Pearl Millet	Sunflower	Pigeonpea
		q/ha	q/ha	q/ha	q/ha
RED SOIL					
Ridge	22	53.7	36.1	11.1	9.3
	80	60.2	34.0	10.1	10.8
Flat	22	56.6	35.0	11.4	9.8
	80	60.6	36.1	10.4	11.7
F VALUE					
Nitrogen rate		7.5*	0.1	8.9*	6.7*
Planting method		0.8	0.2	0.9	1.1
Interaction		0.1	1.7	0.1	0.1
BLACK SOIL					
Ridge	22	35.2	28.1	16.3	3.6
	80	39.1	38.6	16.5	4.5
Flat	22	33.7	29.0	17.6	3.8
	80	41.4	36.5	17.4	4.8
F VALUE					
Nitrogen rate		9.2*	17.4**	0.1	20.0**
Planting method		0.1	0.1	1.6	1.7
Interaction		1.0	0.4	0.1	0.4

Fertilizer: All treatments received 124-kg/ha of 18–46–0 at planting in a band 5-cm to one side of seed; 58-kg/ha of N as ammonium sulfate broadcast ahead of planting for higher N rate.
Varieties: Sorghum, CSH-1; pearl millet, HB-3; sunflower, EC68415; pigeonpea, Pusa Ageti.

FERTILIZATION

Purpose of Study

Chemical fertilizers have played a minor role in rainfed farming systems on the Deccan Plateau. The same is true in the great proportion of rainfed farming in other semi-arid tropics. An integral part of Farming Systems research is exploring the needs for added fertility through chemical fertilizers and the responses of various crops under different soil and management situations.

Fertilizer trials have been part of the research program in the two crop years that have passed since ICRISAT was founded. Fertilizer response on one research site in one country of the semi-arid tropics may not be directly applicable elsewhere. Therefore, we are emphasizing approaches that help us understand the underlying principles that relate to use of chemical fertilizers under the characteristic rainfall conditions.

Description of Experiment

Response data reported here are essentially replicated observations. They are part of the process of familiarization—we are getting acquainted with the soils, climate and crops plus learning about response potentials.

We report here a series of fertilizer response observations on several kharif and rabi crops for two years. Two different soils are involved. The average of replicated yield observations and details of the fertilizer applications, varieties used and previous history of chemical fertilizer on the land are presented in tables throughout this section.

Results

Tables 25 through 29 summarize the data as responses of individual crops to the principal fertilizer elements. In the course of the growing seasons, we noted visual evidence of plant response; these observations will be useful as we design further experiments and learn more about managing crop production in the Hyderabad situation. However, only effects of fertilization as reflected in measured yields are recorded here.

Kharif '72 results. In the 1972 kharif season—on land not previously treated with chemical fertilizers—sorghum responded significantly to both nitrogen and phosphorus fertilizers (Figure 21). With added nitrogen that season, the highest yield was recorded for the 80-kg/ha rate, although it was not significantly higher than 40 N. The same general pattern appeared with both red soils and black soils. The 26-kg/ha rate of phosphorus (60 P_2O_5) produced significant response on both red and black soils; double that rate did not give a further significant increase in yield on either soil.

With pearl millet in the 1972 kharif, both nitrogen and phosphorus stimulated significant increases on both soils. The first 26-kg/ha increment of phosphorus produced a significant response on both soils, but higher applications gave no additional response.

Kharif '73 results. On the red soils, fertilizer responses in 1973 kharif did not duplicate the 1972 patterns. Since the plots were on land that had been uniformly

Table 25. Yield Response of Kharif Sorghum and Pearl Millet to Nitrogen, Phosphorus and Potassium Fertilization on Red and Black Soils, Hyderabad, 1972

Fertilizer Treatment—kg/ha			Soil and Crops			
			Red Soil		Black Soil	
			Sorghum	Pearl Millet	Sorghum	Pearl Millet
N	P	K	q/ha	q/ha	q/ha	q/ha
0	26	0	13.4	12.8	29.2	20.6
40	26	0	25.2	22.4	41.7	23.4
80	26	0	27.9	26.3	46.9	22.4
120	26	0	25.1	24.5	43.5	26.0
160	26	0	26.2	28.4	41.5	28.6
160	52	0	21.5	27.3	46.1	32.5
160	26	50	25.8	26.2	51.0	29.1
160	0	0	18.7	21.5	32.4	14.8
LSD (05)			6.4	5.6	9.3	6.7

Fertilizer : All of P and K and 24-kg/ha of N applied at planting in a band 5-cm to side of seed; balance of N supplied by topdressing of ammonium sulfate.

Varieties : Sorghum, CSH-1; pearl millet, HB-3.

Previous history: These crops were grown on land previously operated by village farmers; chemical fertilizers had not been used.

fertilized the previous year, the general yield level was high and neither sorghum nor pearl millet produced significantly more at any rate of nitrogen or phosphorus. These preliminary results indicate that the 1972 uniform phosphorus application produced an appreciable residual effect. This observation must be investigated further before drawing definite conclusions.

On black soils, nitrogen and phosphorus fertilizers generated significantly higher yields on both sorghum and pearl millet.

Rabi '72–'74 results. Trials with sorghum in the 1972–73 rabi season showed significant response to nitrogen and phosphorus application on both the red and black soils (Table 27).

Table 28 shows the comparative response of sorghum, pearl millet and setaria to fertilization in the 1973–74 rabi season. Sorghum and pearl millet response to phosphorus was greater than setaria. Pearl

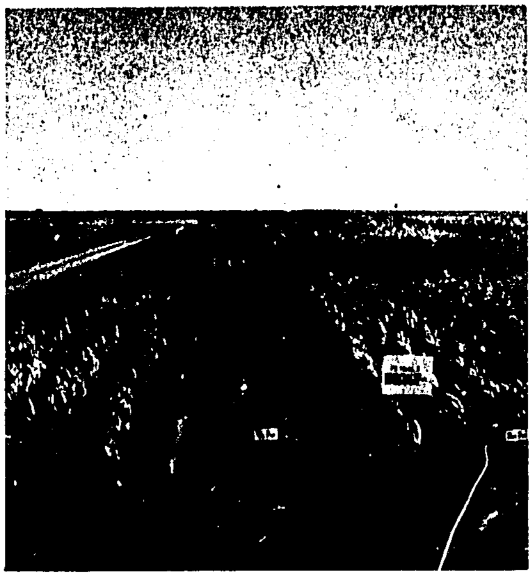


Figure 21. Phosphorus response on red soils was particularly evident on sorghum at early growth stages in 1972 trials.

Table 26. Yield Response of Kharif Sorghum and Pearl Millet to Nitrogen, Phosphorus and Pottassium Fertilization on Red and Black Soils, Hyderabad, 1973

Fertilizer Treatment-kg/ha				Soil and Crops			
				Red Soil		Black Soil	
				Sorghum	Pearl Millet	Sorghum	Pearl Millet
N	P	K		q/ha	q/ha	q/ha	q/ha
0	25	0		46.2	32.0	27.8	33.3
[illegible]	25	0		56.0	35.0	35.0	40.1
80	25	0		56.8	35.3	36.3	43.4
120	25	0		57.5	33.0	40.1	41.7
120	25	50		57.1	36.0	45.0	42.0
120	0	0		51.4	37.5	24.4	33.1
120	25	50	10 Zn	57.5	31.5	46.4	41.5
LSD (05)				NS	NS	8.2	5.4

Fertilizer: All of P and 22-kg/ha of N applied at planting banded 5-cm to one side of seed; balance of N applied as ammonium sulfate; K as potassium chloride and Zn as zinc sulfate, was broadcast and disced in before planting.

Varieties: Sorghum, CSH-1; pearl millet, HB-3.

Previous history: These crops were grown on land that had been cropped to soybean-pigeonpea intercrop and had received a uniform application of 131-kg/ha of 18–46–0 plus 60-kg/ha of N as ammonium sulfate topdressed in 1972; chemical fertilizers had not been used earlier.

Table 27. Yield Response of Rabi Sorghum to Nitrogen, Phosphorus and Potassium Fertilization on Red and Black Soil, Hyderabad, 1972–73

Fertilizer Treatment—kg/ha N	P	K	Sorghum Yields Red Soil q/ha	Black Soil q/ha
0	30	0	14.6	19.2
40	30	0	26.5	32.6
80	30	0	29.6	28.8
120	30	0	30.3	31.8
120	30	50	23.1	32.7
120	0	0	2.2	17.3
LSD (05)			5.0	7.6

Fertilizer : All of P and 27-kg/ha of N applied at planting as 18–46–0 banded 5-cm to side of seed; K as potassium chloride and the balance of N supplied as ammonium sulfate was topdressed 3 weeks after planting.

Variety : CSH-1

Previous history: This crop was grown on land previously cultivated by village farmers; chemical fertilizer had not been used.

Table 28. Yield Responses of Rabi Sorghum, Pearl Millet and Setaria to Nitrogen, Phosphorus, Potassium and Zinc Fertilization on Red Soil, Hyderabad, 1973–74

Fertilizer Treatment—kg/ha N	P	K	+ Zn	Crop Yields Sorghum q/ha	Pearl Millet q/ha	Setaria q/ha
0	25	0	10	35.0	19.8	15.9
40	25	0	10	37.6	24.4	15.2
80	25	0	10	41.7	26.5	18.0
120	25	0	10	42.8	32.7	19.3
120	25	50	10	43.4	29.6	16.7
120	0	0	10	23.0	16.6	11.7
120	25	0	0	41.6	31.1	15.2
LSD (05)				10.4	5.9	2.7

Fertilizer : All P and 22-kg/ha of N banded at planting 5-cm to one side of seed, rest of N as ammonium sulfate. K as potassium sulfate and Zn as Zinc sulfate was broadcast and disced in before planting.

Varieties : Pearl millet, HB-3; setaria, H-1

Previous history: These crops were grown on land that had been farmed without chemical fertilizers before 1972. During 1972–73, 150-kg/ha of 18–46–0 was applied plus 93-kg/ha of N as ammonium sulfate topdress.

millet was more responsive to nitrogen than setaria.

Sunflower and safflower. Table 29 gives results for sunflower and safflower grown in rabi season fertilizer trials in the 1972–73 season. Sunflower gave significant response to nitrogen and phosphorus application on both soils. Safflower responded significantly to nitrogen and phosphorus fertilization on red soil but gave no significant increase to fertilizer on the black soil.

KHARIF IRRIGATION

Purpose of Study

Weather records and experiences of local farmers give ample evidence of the possibility of monsoon drought. We designed an experiment for kharif 1973 in which different levels of irrigation would be tried. The design also included a treatment with no nitrogen fertilizer and an application of 100-kg/ha of N. The irrigation treatments planned were: (1) no supplemental water; (2) optimum irrigation when soil moisture reached 50% of available capacity; (3) one irrigation with 5-cm as "life saving" application; (4) two 5-cm irrigations at "life saving" points.

Description of Experiment

Under the 1973 kharif conditions, only one irrigation treatment was actually applied. The 50% of available capacity point was reached on two occasions on red soils, and 5-cm irrigations were applied to those plots on Sept. 6 and Sept. 21. (In both cases a rain occurred on the following day.) No other red soil plots were irrigated; no irrigation was called for on any black soil plots.

Results

Table 30 reports the results of this trial, in which the nitrogen fertilizer accounts for the principal difference in the yields of all three crops. Sunflower showed a small but significant response to irrigation treatment. Sorghum and pearl millet produced relatively high yields without irrigation and no significant increase occurred on the irrigated plots.

Table 29. Yield Responses of Rabi Sunflower and Safflower to Nitrogen, Phosphorus and Potassium Fertilization on Red and Black Soils, Hyderabad, 1972–73

Fertilizer Treatment—kg/ha			Soil and Crop			
			Red Soil		Black Soil	
N	P	K	Sunflower q/ha	Safflower q/ha	Sunflower q/ha	Safflower q/ha
0	30	0	7.3	7.8	13.7	9.9
40	30	0	9.6	8.9	16.9	12.3
80	30	0	10.9	8.7	17.3	10.2
120	30	0	10.8	9.2	16.2	10.9
120	30	50	9.3	9.9	13.9	8.4
120	0	0	3.3	3.7	12.0	4.4
LSD (05)			2.3	1.2	1.6	NS

Fertilizer : All of P and K and 27-kg/ha of N applied at planting banded 5-cm to side of seed; K as potassium chloride and the balance of N supplied as ammonium sulfate was topdressed 3 weeks after planting.

Varieties : Sunflower, EC68415; safflower, S-11

Previous history: These crops were grown on land that had been farmed without chemical fertilizers before 1972.

Table 30. Effect of Irrigation and Nitrogen Fertilization on Yields of Kharif Sorghum, Pearl Millet and Sunflower on Red Soil, Hyderabad, 1973

Treatment		Crop yield		
Irrigation	Nitrogen kg/ha	Sorghum q/ha	Pearl Millet q/ha	Sunflower q/ha
None	0	40.2	25.5	12.0
Two 5-cm	0	44.6	22.8	16.3
None	100	48.7	33.4	11.2
Two 5-cm	100	52.5	34.8	13.3
F Value:	Nitrogen	13.5**	65.9**	26.0**
	Irrigation	NS	NS	78.9**
	Interaction	NS	NS	9.1*

Fertilizer: Uniform application of 25-kg/ha of phosphorus applied in a band 5-cm from seed in all treatments. 78-N was applied as ammonium sulfate broadcast before planting and 22-kg/ha of N was applied in a band at planting in the 100-kg/ha of N treatments.
Irrigation: 5-cm applications on Sept. 6 and Sept. 21.

ROOT SAMPLING

Purpose of Study

The ability of the plant roots to permeate the soil profile is one of the factors which determines the amount of moisture available to the plant. By investigating the rooting patterns, we can determine which plant species or varieties show the greatest root exploration of a particular soil. We can also determine which management system encourages the deepest rooting of an individual crop.

Description of Experiment

We began a preliminary study this year of the rooting pattern of seven major crops grown in the semi-arid tropics. Four crops were studied in both red soils and black soils: sorghum, pearl millet, chickpea and safflower. Three were investigated only in black soils: sunflower, setaria and wheat.

Our method involved sampling at 15-cm intervals to a total depth of 180-cm and washing out and counting root segments found in 100-cc samples of soil. When we started—in January 1974 during the rabi season—our sampling equipment was a 2.5-cm hand-driven tube. Later a 7.6-cm core-sampling machine was delivered and put to use (Figure 22).

Three replications were obtained for each sampling.

Results

Tables 31 through 35 present the data

Figure 22. A core sampling machine was used for extensive root sampling studies.

from these studies. Figures 23 through 27 portray quantitative distribution of roots.

Rooting pattern varied with the crops and with the soils. In the black soil all crops except setaria penetrated to 180-cm (the greatest depth of sampling). In the red soil, the presence of hard rocky sub-soil or parent material greatly influenced rooting depth. The roots of all four crops extended to at least 150-cms.

As expected, root density was greatest in the upper quartile (0 to 45-cm). Density

Table 31. Penetration and Distribution of Sorghum Roots in Red and Black Soils, Hyderabad, 1974

Soil Depth cm	Red Soil		Black Soil	
	Root Segments No./100-cc of soil	Percent*	Root Segments No./100-cc of soil	Percent*
0 to 15	27	43.4	29	44
15 to 30	29		23	
30 to 45	26		29	
45 to 60	28	39.7	20	29.9
60 to 75	21		18	
75 to 90	26		17	
90 to 105	16	13.7	17	20.7
105 to 120	5		15	
120 to 135	5		6	
135 to 150	4	3.2	6	5.4
150 to 165	2		3	
165 to 180	0		1	

* Percent refers to fraction of total root segments found in a given quartile of the root zone.

Table 32. Penetration and Distribution of Pearl Millet Roots in Red and Black Soils, Hyderabad, 1974

Soil Depth cm	Red Soil		Black Soil	
	Root Segments No./100-cc of soil	Percent*	Root Segments No./100-cc of soil	Percent*
0 to 15	63	63.9	25	49.3
15 to 30	51		24	
30 to 45	45		26	
45 to 60	34	24.9	19	31.6
60 to 75	19		14	
75 to 90	9		15	
90 to 105	8	6.4	9	13.8
105 to 120	4		9	
120 to 135	4		3	
135 to 150	5	4.8	4	5.3
150 to 165	3		2	
165 to 180	4		2	

* Percent refers to fraction of total root segments found in a given quartile of the root zone.

and distribution among the four quartiles differed among crops and between red and black soils with the same crop.

We plan to do more detailed study of rooting pattern, correlating root distribution and water absorption at different depths during the growing season. The observations will be enhanced by soil moisture data taken and correlated as part of this investigation.

Table 33. Penetration and Distribution of Chickpea Roots in Red and Black Soils, Hyderabad, 1974

Soil Depth cm	Red Soil		Black Soil	
	Root Segments No./100-cc of soil	Percent*	Root Segments No./100-cc of soil	Percent*
0 to 15	164	65.5	46	50.9
15 to 30	101		40	
30 to 45	86		26	
45 to 60	60	26.9	24	28.6
60 to 75	45		20	
75 to 90	39		19	
90 to 105	18	6.9	15	15.5
105 to 120	12		10	
120 to 135	7		9	
135 to 150	4	0.7	4	5.0
150 to 165	0		4	
165 to 180	0		3	

* Percent refers to fraction of total root segments found in a given quartile of the root zone.

Table 34. Penetration and Distribution of Safflower Roots in Red and Black Soils, Hyderabad, 1974

Soil Depth cm	Red Soil		Black Soil	
	Root Segments No./100-cc of soil	Percent*	Root Segments No./100-cc of soil	Percent*
0 to 15	35	44.8	31	41.8
15 to 30	25		22	
30 to 45	35		21	
45 to 60	35	36.3	20	31.6
60 to 75	23		17	
75 to 90	19		19	
90 to 105	19	17.0	13	18.6
105 to 120	11		11	
120 to 135	6		9	
135 to 150	4	1.9	7	7.6
150 to 165	0		3	
165 to 180	0		4	

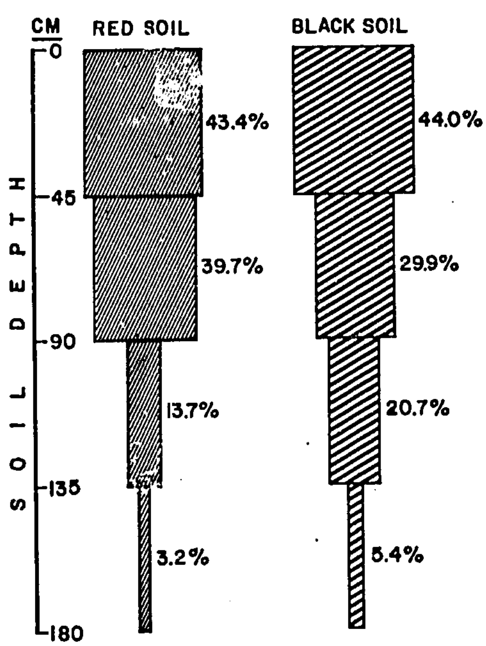
* Percent refers to fraction of total root segments found in a given quartile of the root zone.

Table 35. Penetration and Distribution of Roots of Sunflower, Setaria and Wheat in Black Soils, Hyderabad, 1974

Soil Depth cm	Sunflower Root Segments No./100-cc of soil	Sunflower Percent*	Setaria Root Segments No./100-cc of soil	Setaria Percent*	Wheat Root Segments No./100-cc of soil	Wheat Percent*
0 to 15	52	52.5	54	66.7	46	61.0
15 to 30	38		33		32	
30 to 45	27		35		22	
45 to 60	22	24.8	28	27.9	17	23.8
60 to 75	16		13		14	
75 to 90	16		10		8	
90 to 105	17	15.3	5	5.4	5	8.5
105 to 120	12		3		4	
120 to 135	12		2		5	
135 to 150	10	7.2	0	0	5	6.7
150 to 165	8		0		3	
165 to 180	1		0		3	

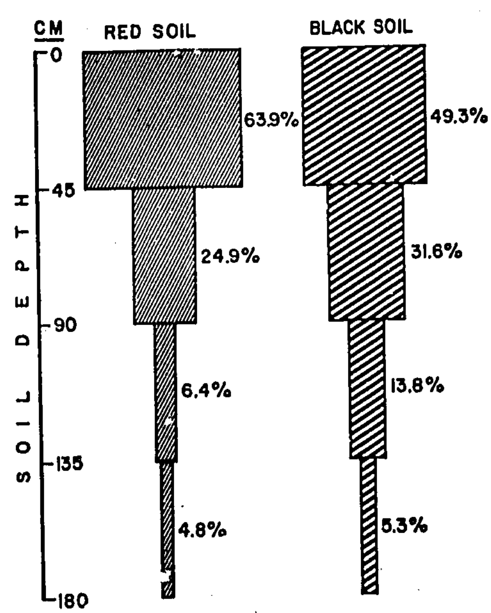
* Percent refers to fraction of total root segments found in a given quartile of the root zone.

Figure 23. Penetration and Distribution of Sorghum Roots in Red and Black Soils.



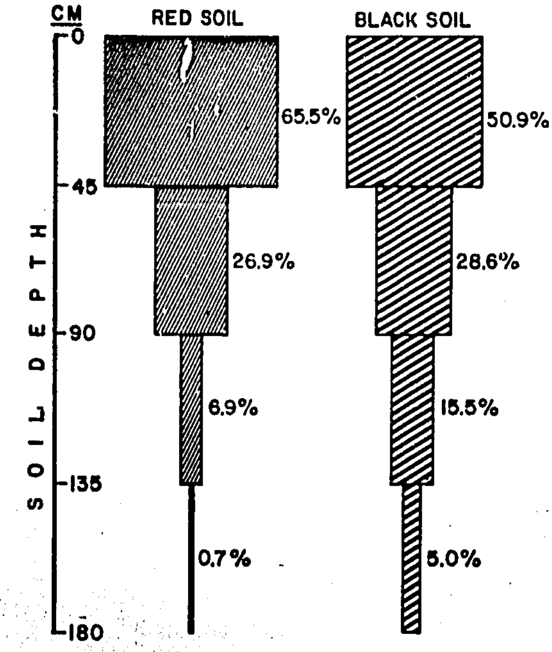
DATA BASED ON TABLE 31

Figure 24. Penetration and Distribution of Pearl Millet Roots in Red and Black Soils.



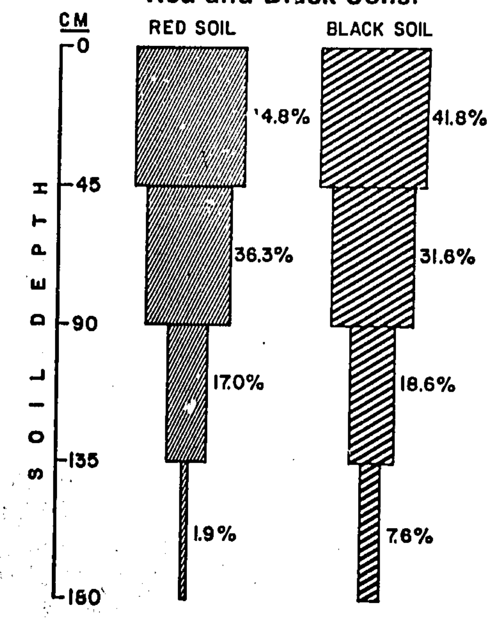
DATA BASED ON TABLE 32

Figure 25. Penetration and Distribution of Chickpea Roots in Red and Black Soils.



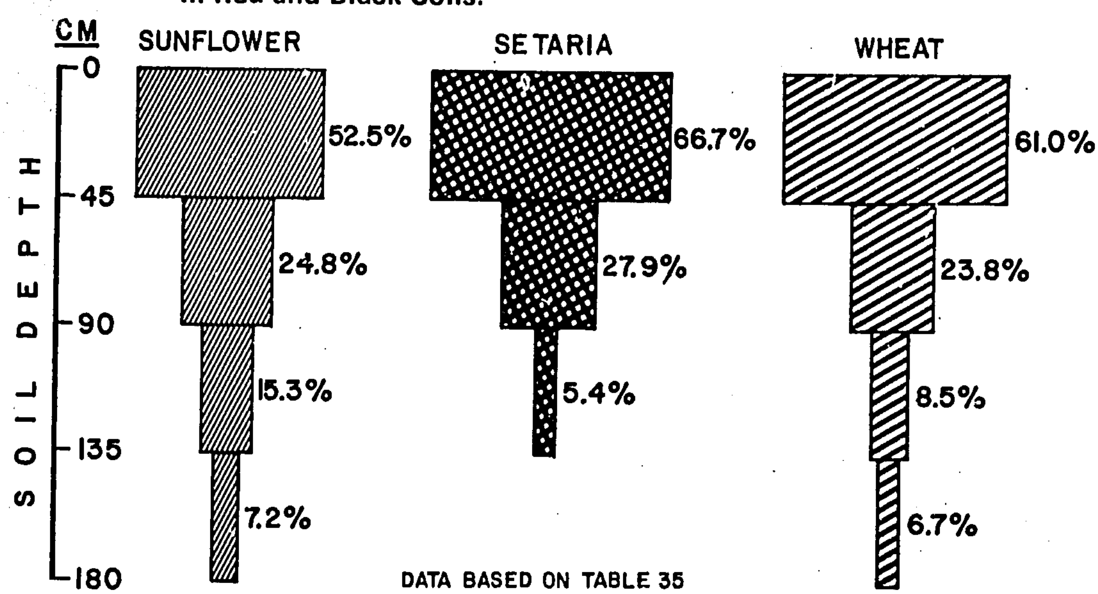
DATA BASED ON TABLE 33

Figure 26. Penetration and Distribution of Safflower Roots in Red and Black Soils.



DATA BASED ON TABLE 34

Figure 27. Penetration and Distribution of Sunflower, Setaria and Wheat Roots in Red and Black Soils.



FARMING SYSTEMS OBSERVATIONS ON RESOURCE MANAGEMENT—IMPLICATIONS FOR FUTURE RESEARCH

INTRODUCTION

New technology on specific production factors has to be integrated into the total farming system. At ICRISAT we feel that land and water management, new varieties, cropping combinations, fertilizers, implements and other innovations should be presented to farmers in a coordinated package rather than as isolated inputs and fragmented knowledge. Our aim is to develop improved *systems* of farming which include a complete program of inputs and recommendations covering the entire production process.

To achieve a practical integration of technological innovations and sound practices, we have selected the watershed as a basic production unit. The watershed provides an opportunity to study alternative systems of farming, particularly in their effects on water utilization. A series of natural watersheds ranging from 3.6 to 15-hectares were used to initiate these studies. New developments from ICRISAT and other research centers throughout the world will be evaluated on a realistic scale in the watersheds and integrated into appropriate systems.

Figure 28 shows the location of the natural watersheds at ICRISAT. We used those designated BW1–BW5 for experiments and observations this year. Watersheds BW6–BW8 will be in production next season. We have started development work on watersheds RW1 and RW2 in the red soils.

Evaluation of the requirements, production effects and water utilization patterns of complete alternative farming systems is a dynamic process. The requirements of crop production systems change continuously and the inputs available for production vary.

International Focus

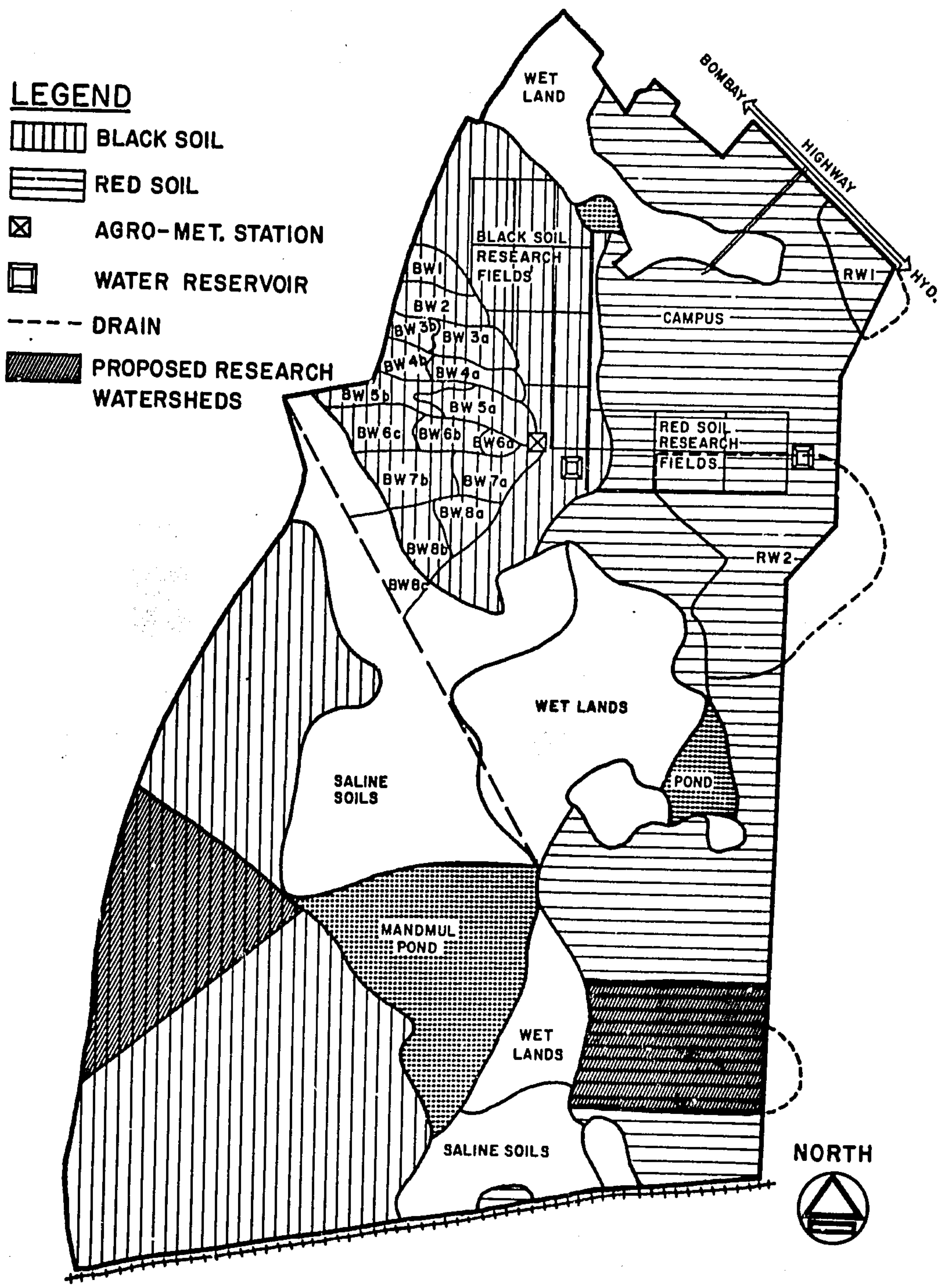
While some of our findings will be site specific, we are using the agro-climatic environment at ICRISAT to generate principles which will assist in the development of integrated approaches to farming in different regions of the world's semi-arid tropics. Presently available simulation and programing techniques will assist in our efforts to adapt principles and technology to other locations. We will cooperate with national and regional programs in their efforts to convert these principles to firm recommendations and packages adapted to local environments.

Objectives of 1973/74 Research

The watershed-based phase of Farming Systems research this year was intended to generate information to provide a basis for more refined research in the future. At present, we lack hydrologic data necessary to study the optimum utilization of rainfall by crops, particularly as it affects the small holding of the farmer.

The quantitative interrelationships between levels of management; control and conservation of soil and water; and systems of cropping are not adequately understood The complex relationships involved in effective utilization of rainfall, drainage, runoff collection and recycling for supplementing available soil moisture to cropping systems also need to be determined. Even less is known about the effect of different levels of soils and water management on the economics of production or the social implications of integrated resource management and new systems of farming. This year's observations have provided basic data and methodology useful in designing future experiments on these factors.

Figure 28. ICRISAT Experiment Station.



UNDEPENDABLE RAINFALL NECESSITATES ALTERNATIVE SYSTEMS

Undependable rainfall patterns are characteristic throughout the semi-arid tropics. Hyderabad data illustrate the problem of too little monsoon rainfall in some years, too much in others, while in most years the seasonal distribution is uneven. High storm intensities resulting in runoff and erosion are a common phenomena.

Drought Risk High

Figures 29 and 30 demonstrate the rainfall pattern at ICRISAT during the last two years.

Variation in total rainfall and in rainfall distribution between seasons makes agriculture exceedingly risk-prone in the semi-arid tropics. Figure 31 shows the variation of rainfall at different rainguages during a selected period at ICRISAT. These variations within even very small areas contribute further to uncertainty in farming.

Too Much Water

An examination of the rainfall distribution and intensities in the semi-arid tropics reveals that the amounts and intensities of rainfall per storm are frequently too great to allow complete infiltration. While infiltration rates of tropical soils vary, precipitation intensities often exceed the combined capacity of surface storage and infiltration. Frequently, infiltration rates are reduced

Figure 29. Rainfall Distribution during the 1972 Monsoon Season at the ICRISAT Weather Station.

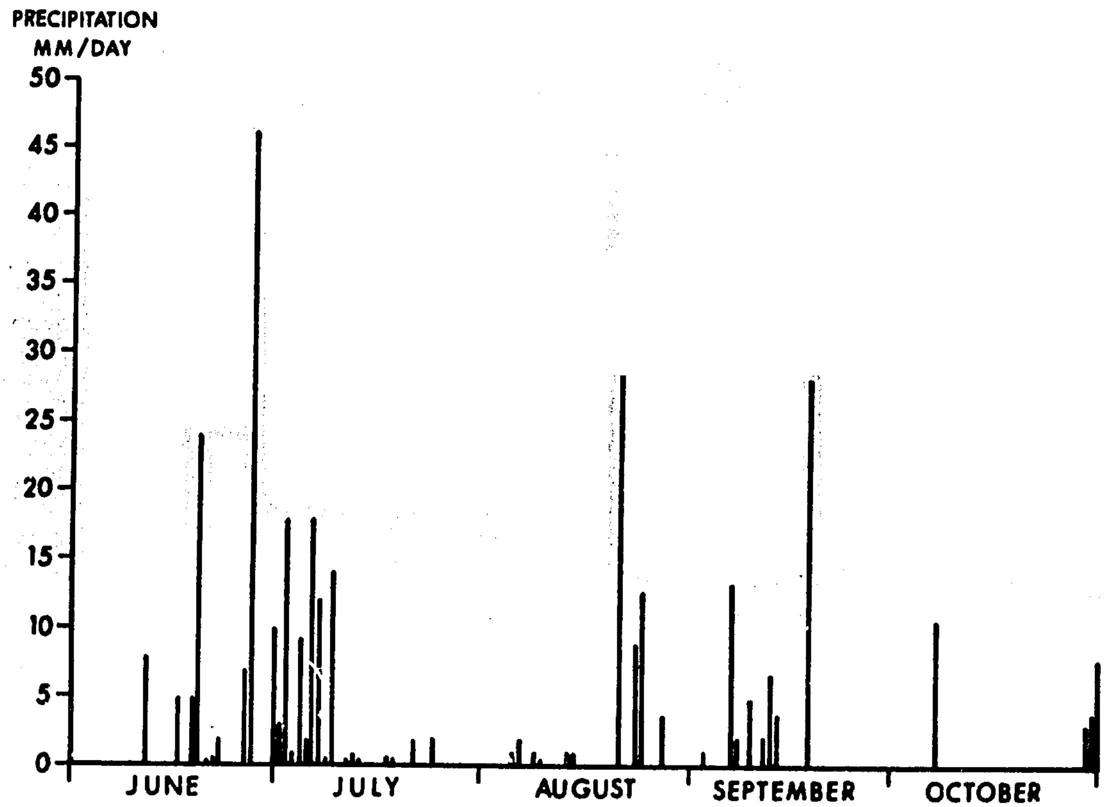


Figure 30. Rainfall Distribution during the 1973 Monsoon Season at the ICRISAT Weather Station.

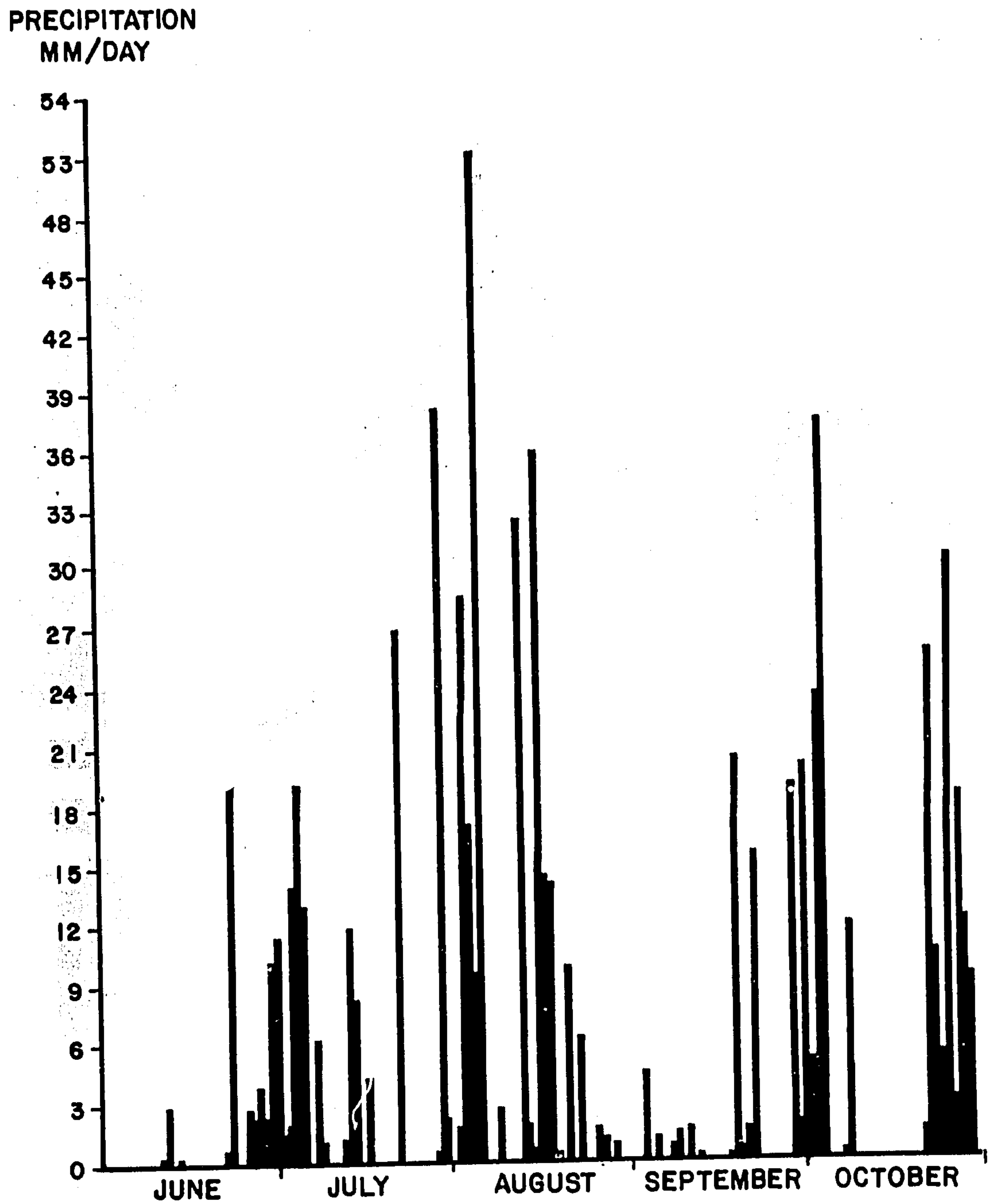
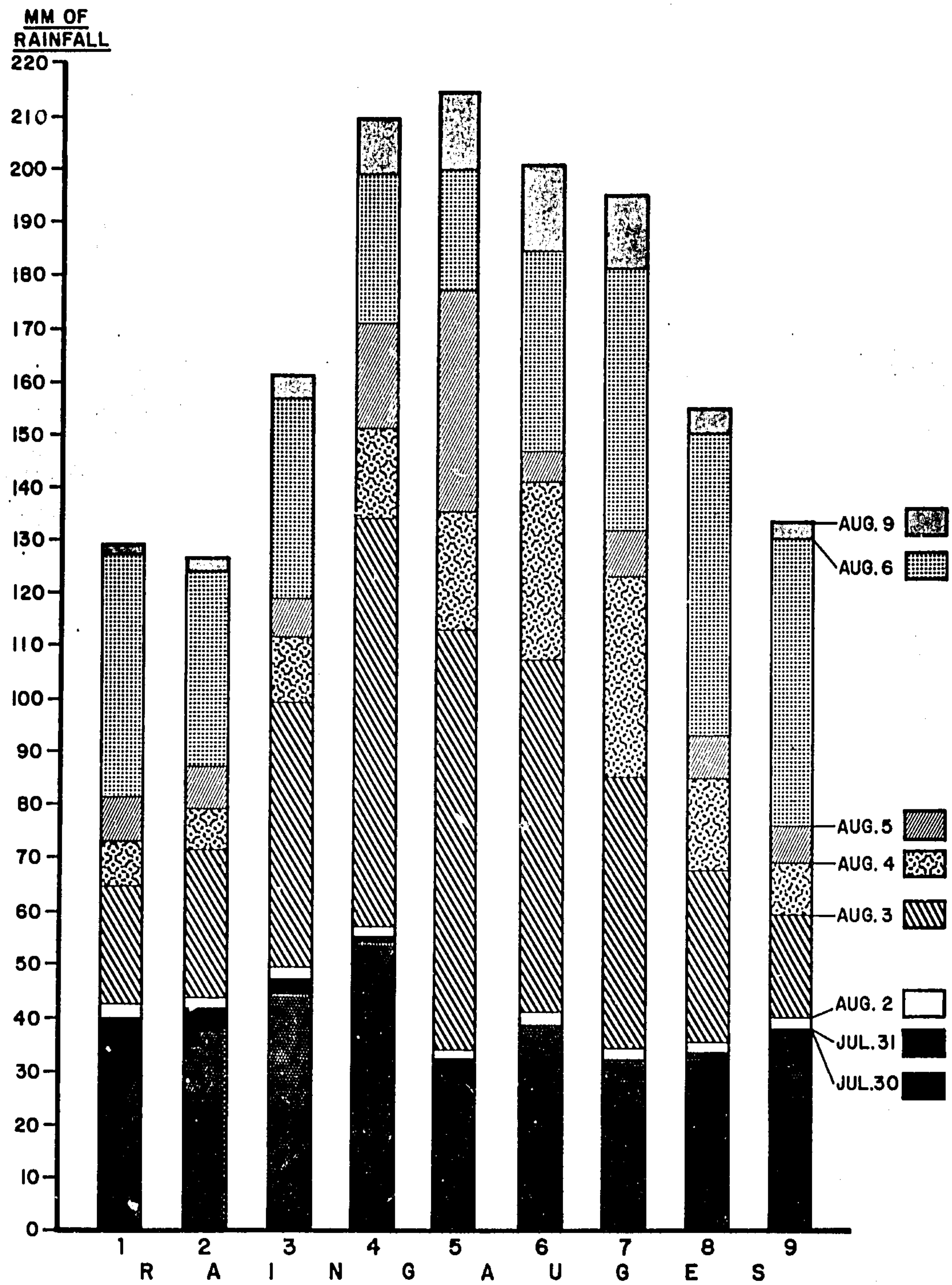


Figure 31. Variation of Rainfall at Nine Raingauges during a Selected Period at ICRISAT, 1973.



further due to surface crusting, lack of vegetative cover, saturation of the profile and other factors.

Traditional Solutions

Field bunding, contour bunding, fallowing and other traditional means of coping with these conditions have been only partially successful in the semi-arid tropics. Historically, the methods employed to utilize runoff water have been inefficient and have benefited only a fraction of the farmers of the semi-arid tropics involving relatively small areas of land. At ICRISAT, we are exploring alternatives which will have a much wider application.

FEATURES OF IMPROVED SYSTEMS

We are monitoring experimental features of improved farming systems on watersheds BW1, BW3 and BW5. Components of trial systems include ridges and furrows which replace traditional contour bunds. The ridges and furrows are graded at varying slopes toward a protected grass waterway which serves as the principal drain for the watershed. In watersheds BW3 and BW5 deep ponds with a comparatively small surface area were constructed for storing runoff. Figure 32 gives a schematic illustration of an improved watershed with the experimental features.

We used tractors and machinery for all farming operations on the improved watersheds. High yielding varieties received optimal levels of fertilizer and pest protection. Favorable moisture conditions at the end of the monsoon made it feasible to grow a second crop on these watersheds.

For comparison, we left watersheds BW2 (4.1-ha.) and BW4 (9.1-ha.) in their original state with small bunds surrounding the individual fields. We used traditional methods of land preparation with bullock power and local varieties and fertilizers to simulate a typical monsoon cropping pattern on BW2. A traditional practice of kharif fallowing was followed on BW4, ploughing with bullocks to control weeds during kharif and planting in the rabi.

While it is too early in the Farming Systems program development to evaluate the alternative systems fully, we have made some preliminary observations on several components.

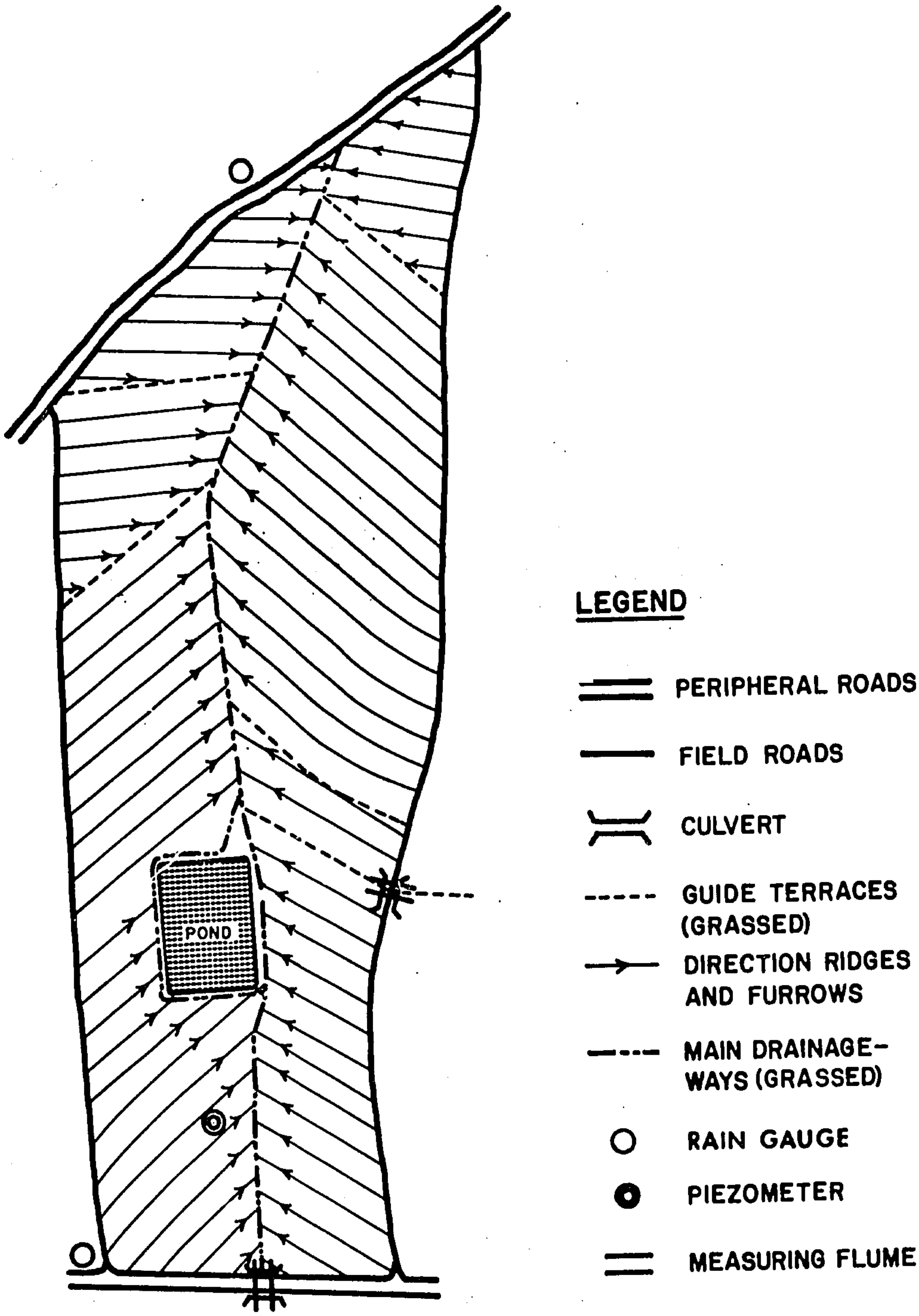
THE RIDGE AND FURROW SYSTEM

Need for System

We are exploring a ridge and furrow system as an alternative or supplement to traditional field bunds and contour bunds for maximizing rainfall infiltration and minimizing erosion. Some of the problems related to traditional bunding methods are.

1. Standard bunds range from 1 to 5-meters in width at the base. A significant land area is taken out of crop production and produces only grass and weeds.
2. To form bunds, the soil immediately adjacent to the bund location is excavated. Poor production results for several years because of this removal of top soil.
3. Drainage problems occur above the bund where water collects. The method of construction which leaves a depression in the topography adjacent to the bund contributes to this problem (Figure 33).
4. The bunds do not create an even infiltration of rainfall within individual fields. Water collects above the bund and infiltrates in that location which often does not amount to more than 10% of the total area of the field.
5. Internal erosion occurs within bunded fields.
6. Bunds are often constructed along property lines rather than contour lines. This practice aggravates soil erosion problems rather than lessening them.
7. Considerable maintenance is required

Figure 32. Schematic Drawing of a Watershed in Ridges and Furrows with a Runoff Storage Facility.



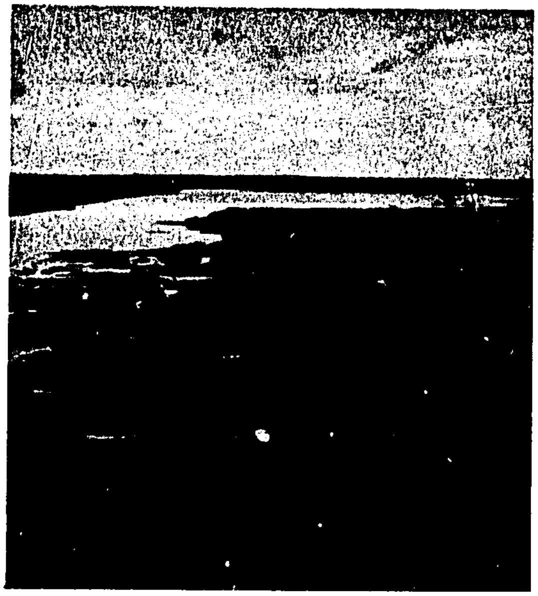


Figure 33. Water collects above traditional field bunds causing drainage problems. Internal erosion within bunded fields remains unsolved with this system.

to prevent breakthroughs or breaches of the bunds, particularly on the black soils. Many bunds in the semi-arid tropics are in a perpetual state of disrepair.

8. All these factors contribute to reduced production after bunds are constructed.

Description of Ridge and Furrow System

Figure 34 gives a schematic cross-section of the ridge and furrow system. A photograph of the system as it actually was implemented at ICRISAT is presented in Figure 35. Examination of these illustrations reveals the ridges function as "mini-bunds" restricting water from flowing directly down the slope.

We have produced ridges and furrows with both modern equipment and bullock-drawn implements (Figure 36). The overall slope of the ridges and furrows is adjusted by manipulating the angle of the ridge in relation to the natural topography. Figure 32 shows how this system can be used to achieve a similar overall slope within a watershed with areas of varying slopes.

Figure 34. Cross-section of Ridge and Furrow System.

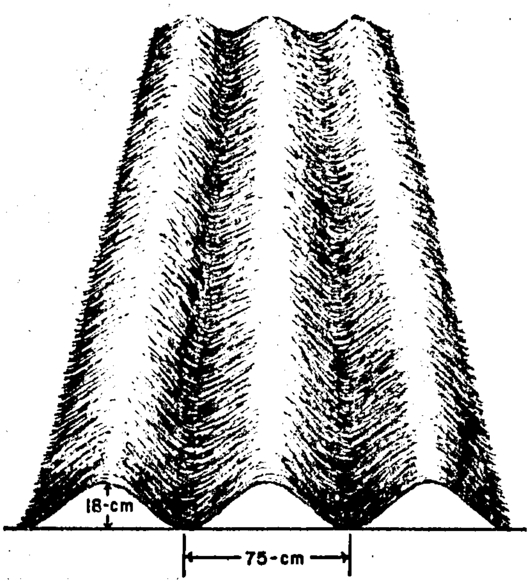


Figure 35. Ridge and furrow system at ICRISAT.

Figure 36 Ridges and furrows produced by bullock power

Preliminary Evaluation

We gathered soil moisture, erosion and runoff data to evaluate the ridge and furrow system and variation in slopes. The hydrologic data are summarized in Table 36.

Runoff. As expected, the two traditional watersheds, BW2 and BW4, had relatively small amounts of runoff. This is because of the "internal storage capacity" of this system. Water collects above bunds in individual fields causing drainage problems. These conditions affected crops in BW2 and tillage operations in BW4. An estimate of the total internal storage capacity, if converted to runoff, would increase total runoff on BW4, for example, to approximately 90-mm. Table 36 shows the quantity of surface runoff increased with progressively steeper average furrow slopes.

This year's observational studies provided useful guides for designing detailed experiments on optimum slope. We have more clearly defined the range of slopes for further evaluation under the rainfall and topographical conditions of the black soils at ICRISAT. Slopes between 4 and 8% appear to offer an acceptable compromise between considerations involving infiltration, runoff, erosion and land smoothing (Figure 37).

Drainage. One important purpose of a ridge and furrow system is to provide adequate drainage on black soils during long continuous wet periods, common in the monsoon season. No serious drainage problems occurred during such periods this year, even under low slope conditions. Watershed BW1 with a .6% slope compared favorably with ridge and furrow systems of steeper slope. We did observe some drainage problems on rabi crops which were planted *flat* later in the year due to delayed monsoon rainfall in October.

Erosion. Table 36 shows that erosion was slight this year. On watersheds BW1 and BW3b with average slopes of less than .8%, erosion amounted to only about 3,000-kilos of soil per hectare. On steeper slopes erosion increased considerably.

While erosion figures on a total watershed basis from bunded fields were similar to those under the ridge and furrow alternative, we observed serious erosion within individual fields. Eroded material was deposited on the less steep portions of a field or above bunds (Figure 38).

No serious localized erosion occurred in watersheds with ridges and furrows, except where furrow slopes exceeded 2%. Excess water in these watersheds is led from higher areas in small streamlets. It travels at relatively low velocities. The system prevents formation of concentrated flows of water. Preliminary evidence indicates a ridge and furrow system maintains more soil at its original location than do systems of field bunds.

Infiltration. We analyzed a large number of soil samples for moisture to determine if the ridge and furrow system provided a more even distribution of infiltration. However, the total storage capacity of the profile was satisfied at most times during the season because of the favorable rainfall distribution so the data collected cannot give an accurate measure of infiltration differences.

We plan further tests to check for differences between lower and higher areas of the watersheds. We will also repeat tests of samples taken along individual furrows to determine if the small moisture differences expected during suboptimal moisture conditions can be measured.

Contour and graded bunding. Testing of some of the more conventional

Figure 37. An ICRISAT Farming Systems scientist records runoff data from a Parshall Flume on improved watershed BW1.

Table 36. Hydrologic Data from Seven Watershed Units, Hyderabad, June 1—Oct. 31, 1973

Watershed		Slope[2]	Rainfall	No. of Runoff Storms	Runoff		Erosion
Code	Area						
	(ha)	(%)	(mm)		mm	% of P	(T/ha)
BW1	3.5	.6	731	21	45	6.2	3.0
BW2	4.1	1.0—1.5[3]	735	15	11	1.5	2.2
BW3A[1]	4.4	1.1	739	—[4]	71	9.6	8.2
BW3B	2.1	.8	734	16	47	6.4	2.9
BW4	9.1	1.0—2.0[3]	739	22	59	8.0	3.9
BW5A[1]	6.5	1.7	757	—[4]	91	11.9	11.3
BW5B	8.1	1.8	755	26	122	16.1	13.3

[1]Water storage facilities were constructed in watershed units BW3A and BW5A. The BW3A unit has a storage capacity of .40-ha/m from which 1.4-ha were irrigated. In BW5A 6.7-ha were irrigated from a .42-ha/m facility.

[2]Except for BW2 and BW4, the slopes indicated are average slopes of ridges and furrows on an entire watershed. They are measured along furrows from the topographically higher point towards the outflow location at a drain. Minimum earth movement has been a self-imposed restriction on watersheds BW1, BW3 and BW5 so considerable variation exists around the average. This is true not only when comparing furrows in different areas of the same catchment but also along many individual furrows.

[3]Catchments BW2 and BW4 were maintained in their original layout and topography. Although the average slopes of the land on the basis of the entire watershed were in the ranges indicated, real slopes on individual bunded fields were less. A continuing process of erosion on these watersheds has resulted in some degree of "levelling" of separate fields. The existing bunds create an internal storage capacity in the watershed.

[4]Although the total runoff collected was measured, no Parshall flumes were installed at the tank inlets. Therefore, the exact number of runoff producing storms for catchments BW3A and BW5A is not known.

soil and water conservation measures of the semi-arid tropics was not included in this year's exploratory management treatments. We will test the effects of graded bunding and other conservation techniques in future experiments.

Conclusions. A critical comparison of the ridge and furrow method to the traditional system of bunded fields has to await the results of additional seasons. The responses of different management systems under varying climatic conditions need to be monitored more closely. However, at this stage it appears feasible to design ridge and furrow systems which give these advantages:

1. Total runoff is less or about the same as occurs with bunded systems.
2. Infiltration of high intensity rain at the actual location where it falls is increased.
3. Drainage problems are reduced.
4. Erosion within individual fields is reduced.

GRASSED WATERWAYS

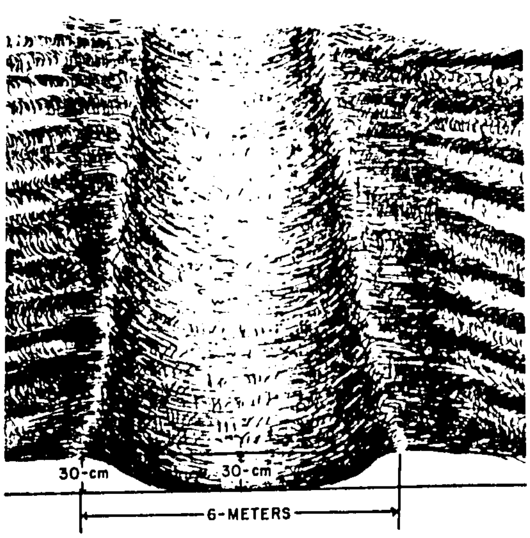
Need for System

Main drainage ways in the improved system watersheds have to meet several criteria. First they have to conduct runoff, often at fairly high velocities, with a minimum of erosion. To gain acceptance, we feel the waterways must be a productive part of the farming system and not interfere with

Figure 38. Internal erosion within bunded fields is particularly evident during monsoon fallowing.

ploughing or other farming operations. Present design considerations took these factors into account.

Figure 39. Cross-section of Experimental Waterway.



Description of Grassed Waterway

We have designed waterways using a principle which can be adapted to the requirements of individual watershed areas. Figure 39 shows a schematic cross-section of an experimental waterway. Figure 40 shows actual waterways at ICRISAT at different times during the season.

Preliminary Evaluation

We tested *Dicanthium annulatum*, *Cenchrus setigerus*, *Cenchrus ciliaris*, *Chrysopogon fulvus*, *Cynadon doctylon*, *Digiteria* and *Brachiaria mutica*. Hybrid Napier, "Paragrass," pearl millet and local grass sod for various properties. We studied the original stand establishment, erosion resistance, the ability to withstand prolonged wet conditions, quick regeneration after the dry season and the production of quality fodder.

Stand establishment. We encountered serious difficulties obtaining a reasonable stand before runoff started eroding the center section of the drainage ways, particularly where slopes exceeded 1% Direct seeding early in the monsoon failed. Planting grass seedlings, previously sown in irrigated seedbeds, at the end of the dry season, appeared not to be practical as supplemental water is required for a few weeks. We tried direct seeding grasses in a mixture with fast establishing pearl millet but success was limited.

We finally resorted to using well-

Figure 40. Grassed waterways at the beginning and end of the monsoon season.

established grass, locally available from old pond beds, to protect the center sections of the steeper parts of the ditches. The side slopes were planted to seedlings of other grass varieties. This method proved successful in preventing erosion at the runoff intensities experienced this season even where drain slopes exceeded 2%. We plan to investigate mulches and different seed mixtures next season to find methods for early grass establishment which do not require irrigation.

Erosion performance. We evaluated erosion resistance for sections of 50-meters of the drains which were planted to different grass varieties. A local grass sod, *Dicanthium annulatum*, and *Cenchrus ciliaris* performed well for the center of the drains. *Cenchrus ciliaris*, *Digiteria* and Hybrid Napier proved reasonably satisfactory on the side slopes.

Production. Drainage way grasses produced substantial fodder, particularly in watershed BW1. We made four cuttings and collected seeds from the last cutting. *Cenchrus ciliaris* ranked first in total fodder production with about 82-q/ha (green weight). *Cenchrus setigerus* ranked second with 71-q/ha. *Dicanthium annulatum* produced 62-q/ha and *Chrysopogon fulvus* placed fourth with 35-q/ha. We plan further production tests next season.

COLLECTION, STORAGE AND RECYCLING OF RUNOFF

Need for System

Small ponds have been used to collect runoff for centuries in many parts of the semi-arid tropics. Traditionally, however, these ponds are shallow, covering a large land area and evaporation losses are high. Poor land management in areas above the storage facilities contributes to rapid silting. Frequently, the use pattern involves growing paddy, a very inefficient crop in a water-scarce environment. Stored water is commonly used below the pond on an area of land which typically is a fraction of the size of the catchment area which contributed the runoff. Improper water management often leads to low water use efficiencies, water-logged soil conditions and salinization in the small, irrigated areas in these traditional systems.

Description of Storage Alternative

The ponds which we constructed in the black soil watersheds differ markedly from

Figure 41. Cross-Section of Experimental Pond.

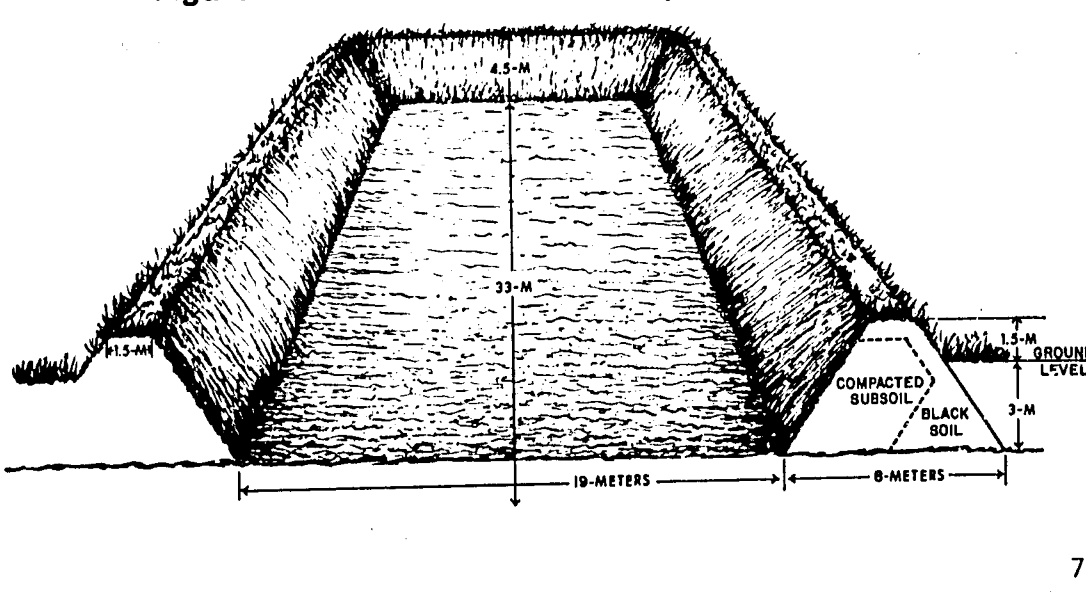


Table 37. Evaporation and Seepage at Four Stage Heights in the BW5A Runoff Storage Pond, Hyderabad 1974.

Date	Met. Station Evapn.	BW5 Pond Evapn. (I)	Fall in Staff Gauge Reading (II)	Seepage (II-I)
	mm	mm	mm	mm
Oct. 10	3.2	2.8	5.0	2.2
Oct. 11	5.0	4.0	6.0	2.0
Oct. 12	5.7	4.0	5.0	1.0
Oct. 13	5.0	4.0	5.0	1.0
Oct. 14	5.0	4.5	5.0	0.5
Oct. 15	5.5	4.7	6.0	1.3
Oct. 16	5.3	4.0	5.0	1.0
Oct. 17	4.0	4.0	5.0	1.0
Oct. 18	5.2	4.0	5.0	1.0
Oct. 19	6.8	6.0	7.0	1.0
Total	50.7	42.0	54.0	12.0

Staff gauge reading Oct. 9: 335.5 Oct. 19: 330.1 — Average seepage rate per day 1.2

Date	Met. Station Evapn.	BW5 Pond Evapn. (I)	Fall in Staff Gauge Reading (II)	Seepage (II-I)
	mm	mm	mm	mm
Nov. 13	3.0	1.8	3.0	1.2
Nov. 14	3.0	1.0	4.0	3.0
Nov. 15	4.0	3.0	5.0	2.0
Nov. 16	4.0	6.0	8.0	2.0
Nov. 17	5.0	2.5	6.0	3.5
Nov. 18	4.8	5.5	10.0	4.5
Nov. 19	5.0	5.0	7.0	2.0
Nov. 20	4.0	2.9	4.0	1.1
Nov. 21	4.0	4.0	5.0	1.0
Nov. 22	4.3	4.0	6.0	2.0
Total	41.1	35.7	58.0	22.3

Staff gauge reading Nov. 12: 385.5 Nov. 22: 379.7 — Average seepage rate per day 2.2

Date	Met. Station Evapn.	BW5 Pond Evapn. (I)	Fall in Staff Gauge Reading (I)	Seepage (II-I)
	mm	mm	mm	mm
Nov. 23	6.0	5.0	7.0	2.0
Nov. 24	5.7	3.5	7.0	3.5
Nov. 25	4.9	3.6	6.0	2.4
Nov. 26	5.3	5.0	7.0	2.0
Nov. 27	5.0	4.0	6.0	2.0
Nov. 28	4.0	4.0	6.0	2.0
Nov. 29	5.0	4.0	6.0	2.0
Nov. 30	4.0	4.0	5.0	1.0
Dec. 1	4.6	3.9	4.0	0.1
Dec. 2	4.5	2.4	7.0	4.6
Total	49.0	39.4	61.0	21.6

Staff gauge reading Nov. 22: 379.7 Dec. 2: 373.6 — Average seepage rate per day 2.2

Date	Met. Station Evapn.	BW5 Pond Evapn. (I)	Fall in Staff Gauge Reading (II)	Seepage (II-I)
	mm	mm	mm	mm
Dec. 19	4.5	3.0	4.0	1.0
Dec. 20	4.5	4.0	4.0	—
Dec. 21	5.0	3.0	3.0	—
Dec. 22	4.7	4.0	4.0	—
Dec. 23	4.0	4.0	4.0	—
Dec. 24	4.6	4.0	4.0	—
Dec. 25	4.3	2.8	3.0	0.2
Dec. 26	4.0	2.8	3.0	0.2
Dec. 27	5.0	4.0	4.0	—
Dec. 28	4.0	4.0	4.0	—
Total	44.6	35.6	37.0	1.4

Staff gauge reading Dec. 18: 254.8 Dec. 28: 251.1 — Average seepage rate per day 0.1

conventional pond design. Figure 41 shows a schematic cross-section of the experimental pond. Figure 42 shows the pond at different times during the season. The primary departure from conventional pond design involved greater depth (4.0-M) and a relatively small surface area taking only a small land area out of production.

Preliminary Evaluation

Evaporation. We collected evaporation data for the BW5 pond from a floating evaporation pan and staff gauges. Table 37 gives results for four ten-day periods during which no rainfall occurred.

The evaporation rates measured in the pond compare favorably with those measured at the agro-meteorology station. An approximate reduction of 20% occurred over the period. This comparatively low rate was presumably due to reduced wind velocities at the pond surface and lower water temperatures because of the greater depth.

Runoff was stored in the BW5 pond from 27 July 1973 to the end of January 1974. With an average total loss of about 5-mm/day during this period, the seasonal water loss would amount to approximately 90-cm, less than 25% of the quantity collected. Losses are appreciably higher with conventional, shallow ponds. Since evaporation accounts for most of the loss, recycling runoff earlier in the post-monsoon season can reduce the losses further. We will make additional efforts to improve upon the design of water storage facilities to reduce both evaporation

Figure 42. ICRISAT storage facility for harvesting runoff.

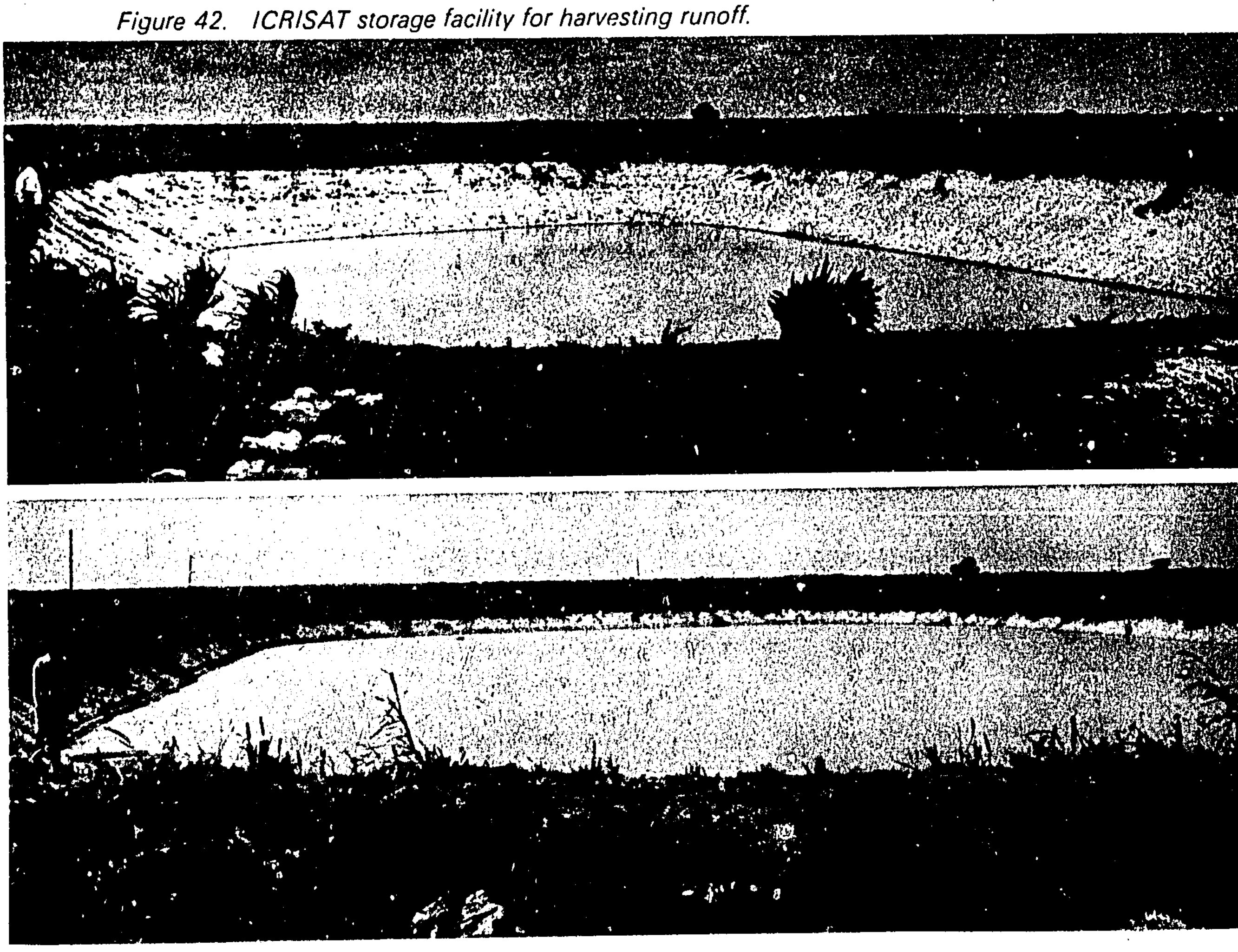


Figure 43. ICRISAT constructed its first water storage facilities by machine to begin the 1973 research program immediately. As the report year ended, we launched experiments using hand-labor and bullocks to construct ponds.

loss and pond construction costs (Figure 43).

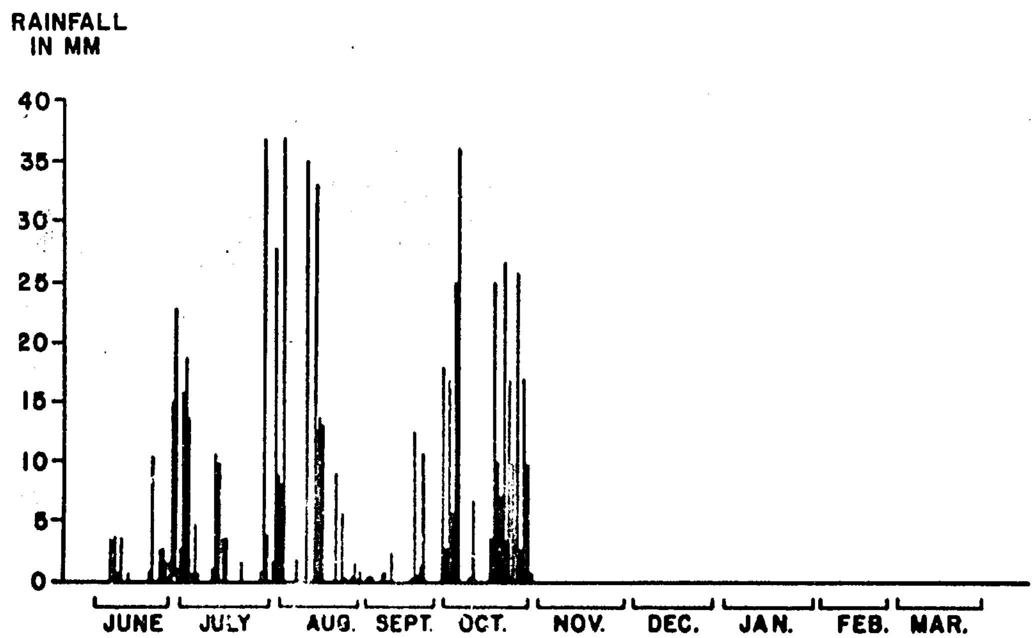
Seepage. Table 37 also gives data on seepage losses. At near maximum capacity (staff gauge reading of 4.0-M), the seepage rate amounted to just over 2-mm/day. Piezometer data also demonstrate seepage was minimal. We found no indications of a substantial rise in groundwater due to the gradual filling of the pond from July 27 to October 31 or of appreciable decreases when water was used from the storage pond (Figure 44). The subsoils found in the black soil area at ICRISAT (and in many other black soil regions) apparently forms a natural sealer for ponds even when the water table is several meters below the bottom of the ponds. We will investigate the more difficult problem of sealants for ponds located on black soils with less favorable subsoils and on the red soils next year.

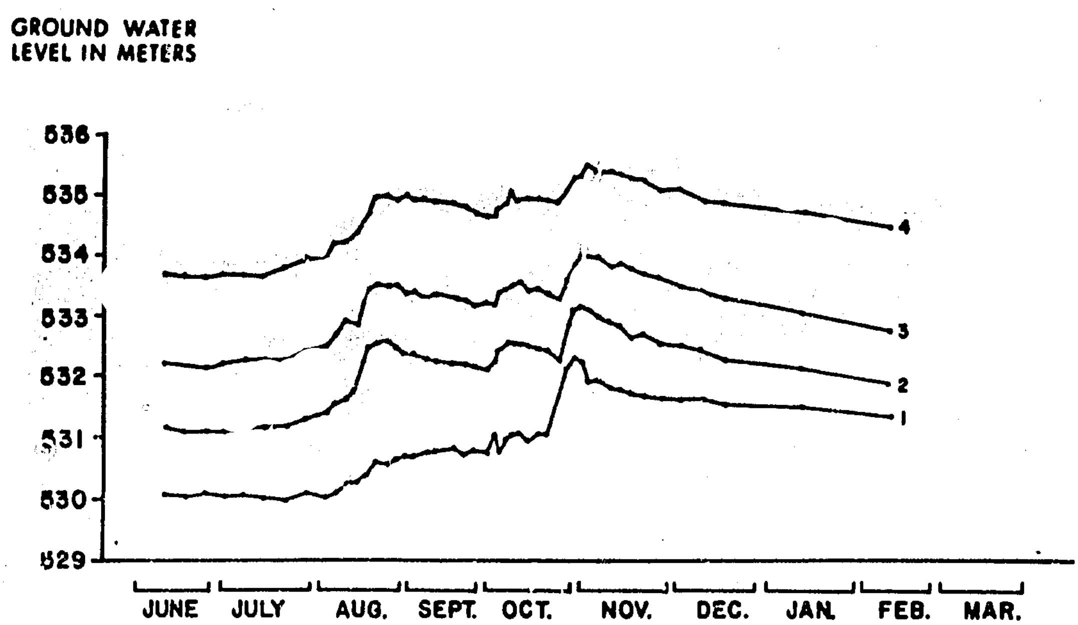
Recycling. We feel the efficient use of runoff through recycling water back on the watershed can make a significant contribution to reducing risk in dryland crop production. While we have run only preliminary experiments to determine the optimum use of stored water, greatest potential appears to be in life-saving water applications to relieve relatively short-duration droughts during the kharif or application early in the rabi to extend the growing season. This procedure would use stored water before evaporation rates increase substantially. Further research is needed to determine the crops and methods which make the best use of this potential.

PRODUCTION OBSERVATIONS

Comparison of the total systems developed on the various watersheds is well beyond the scope of this year's "development stage" observations. However, we did gather some system-wide data on the water balance and crop production as a first step in developing

Figure 44. **Groundwater Levels at four Piezometers in the Black Soil Research Watersheds Compared to Monthly Rainfall, Hyderabad, 1973–74.**





criteria by which systems could be evaluated in subsequent years. Observations on these data are reported to give an indication of the direction of future research.

Cropping System

We superimposed an identical cropping system of about 40% pearl millet and 60% sorghum on each watershed during the monsoon season to facilitate comparisons. Watershed BW4 was fallowed during the monsoon followed by a traditional rabi cropping system.

Some parts of the watersheds were used for experimental plots. Results from some of these trials are reported in the previous section.

We recorded average yields from all crops grown on the black soil watersheds during both the kharif and rabi seasons. These observations were made to provide general insights into productive areas of research and to give us some guidelines about yield potential under present technology.

Traditional Kharif Cropping

The traditional kharif cropping system simulated on watershed BW2 produced almost no grain, a substantial quantity of stalks (fodder) was harvested, 153-q/ha for sorghum and 95-q/ha for pearl millet. Kharif cropping is the most widely used practice in the Hyderabad region. Possible reasons for the poor results were:

- Rain damage due to a shift of the high rainfall period from the usual September period to October.
- The low levels of human labor, animal or mechanized power, fertilizers and other inputs and the use of traditional, tall varieties.
- Poor drainage conditions due to stagnant water in local depressions and above field bunds.

Rabi Cropping

The traditional rabi cropping system simulated on watershed BW4 produced sorghum grain yields of about 13-q/ha, substantially exceeding production under traditional kharif cropping. However, fodder yields under rabi cropping were reduced with less than 50-q/ha of sorghum stalks. The watershed had to be ploughed four times during the monsoon season to control weeds.

Moisture conservation effects of fallowing. We measured soil moisture of both cropped and fallowed watersheds at the end of the monsoon. There was hardly any difference between the total quantity of moisture present in the profile of the watersheds cropped during the monsoon and the moisture level of the fallowed BW4 watershed (Figure 45). Efforts to conserve moisture by fallowing had little effect in the 1973 season.

The total quantity of moisture present in the upper 180-cms of the profile of watershed BW4 in early July was about 600-mm. In early November this quantity had increased to only 825-mm. More than two-thirds of the 739-mm of total precipitation received on watershed BW4 was lost for crop production primarily through deep percolation, evaporation and runoff. This loss occurred though watershed BW4 was ploughed repeatedly to prevent transpiration losses from weeds.

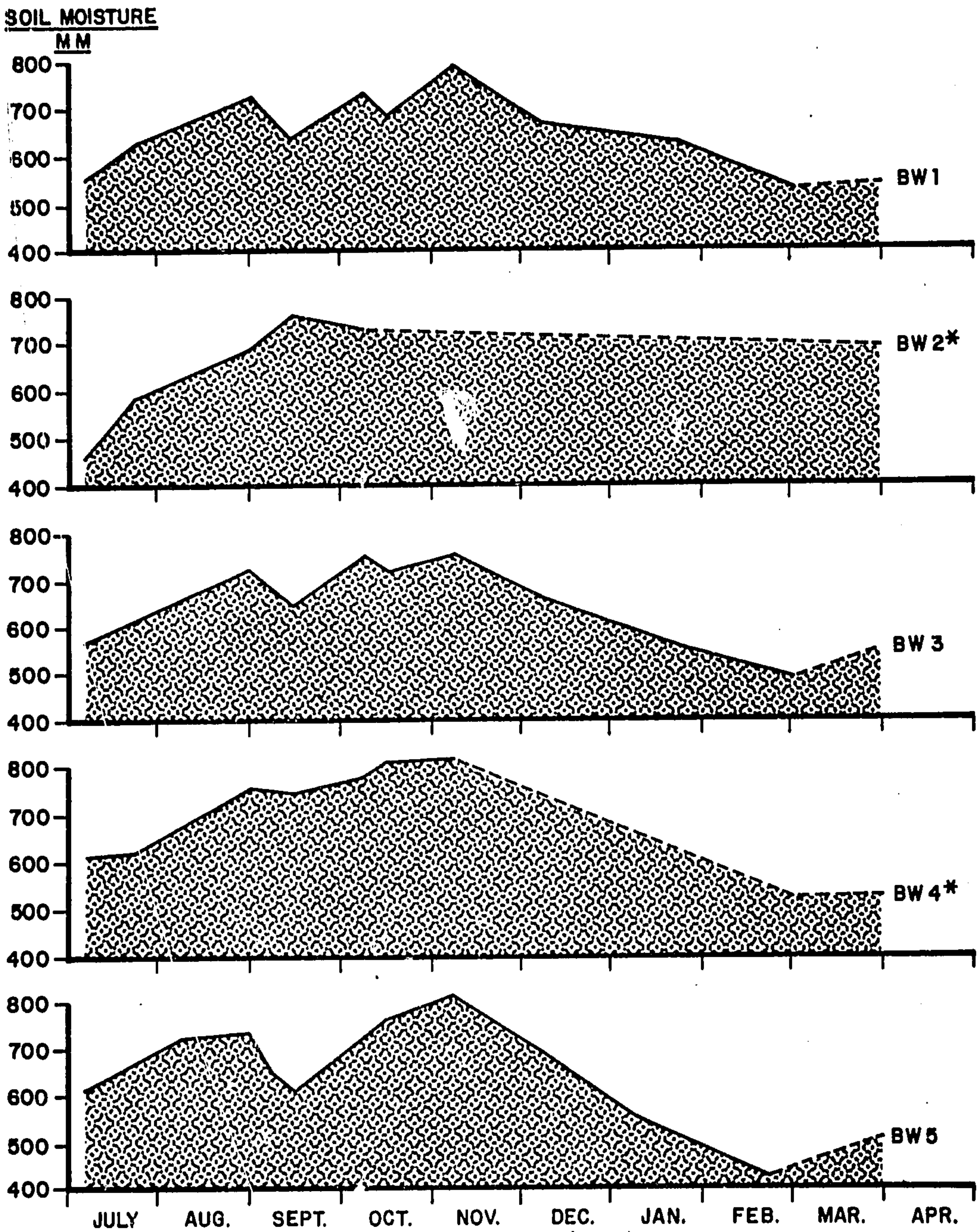
Improved Systems

The production figures for the systems on the remaining three watersheds were considerably higher than those recorded for the traditional systems. Crops on watershed BW3, where slopes of ridges and furrows ranged from 0.8 to 1.1%, produced the highest yields; in kharif about 37-q/ha for both sorghum and pearl millet grain. In the rabi season the highest yield, 23-q/ha, was obtained with an early planting of safflower.

Conclusions on Production Differences

While conclusions must be qualified because of differences between watershed systems in development costs, soil depths, fertility and other variables and because of favorable weather this season, we feel this

Figure 45. Soil Moisture (mm) of a 180-cm Deep Profile in five Watersheds at Several Dates in 1973–74.



* SOIL MOISTURE SAMPLES ON BW 2 AND BW 4 WERE TAKEN ONLY AT THE BEGINNING AND END OF THE POST-MONSOON SEASON

year's results demonstrate a potential exists to increase yields several-fold over present production in large areas of the semi-arid tropics.

The long-term production benefits from reduced erosion through improved land and water management techniques will not be reflected in one or perhaps many seasons' production data. However, control of this major limiting factor of production in the semi-arid tropics could reverse the present trend of steady deterioration of agricultural potential of vast areas of land. Together with farm ponds, drainage systems, use of grasses, trees, and other perennials and similar long-term capital improvements, control of erosion could ultimately affect the ecology of entire regions. A steady improvement in management of these factors could reclaim large areas of land for crop production.

FUTURE PRODUCTION RESEARCH ON WATERSHEDS

Trees and grasses. We are testing various fruit trees in areas near the watershed storage ponds. Grasses have been tested for a specific use in the waterways. We plan more comprehensive investigations of trees and grasses, particularly in the red soil watersheds where perennials will have an important role in the farming systems.

Economics. Time and cost factors related to watershed development, land preparation, cultivation, harvesting, threshing and other production inputs were beyond the scope of this year's preliminary analyses. We plan to collect detailed data on variable costs and returns of alternative systems in future studies.

Engineering. We found an immediate need for research on animal powered implements. Development of machinery and implements, suited to the labor and power conditions and soils of the semi-arid tropics, will be a major focus of future research.

Future cropping pattern experiments. We will superimpose an identical set of cropping patterns called Cropping Complex 1 on all black soil research watersheds during the next few years. Each cropping pattern will occupy 1/5 of the area of a watershed. Crop Complex 1 consists of these five cropping patterns:

1. Pigeonpea with several intercrops
2. Sorghum with several rabi crops
3. Pearl millet with several post-monsoon crops
4. Sunflower with several relay rabi crops
5. Maize with several relay rabi crops

PRELIMINARY OBSERVATIONS ON THE WATER BALANCE

We have collected data on five black soil watersheds for less than one year. This period is insufficient to draw conclusions on watershed hydrologic behavior. The information collected this season has served its purpose of raising questions and providing guidelines for future research. We plan further studies to gather accurate data on various phases of the hydrologic cycle, particularly soil moisture, evapotranspiration, groundwater and erosion.

Measurement problems. It was not feasible to measure all components, directly or indirectly, and to obtain a closed water balance in the past season. We were not able to gain an indication of errors from discrepancies in the water balance equation because we lack specific information about evapotranspiration throughout the crop season and about deep percolation to groundwater during the monsoon.

Groundwater. Extensive sampling and piezometer data indicate that the watersheds are not separate units of the groundwater basin. The groundwater in the entire black soil watershed area appears to be subject to influences of the much larger Mandmul basin in which most of the experiment station is located.

The initial data indicate that the groundwater table in most of the black soil watershed area is too deep to influence the moisture status of the root profile. Deep percolation can be estimated at about 100-mm on the basis of observed changes in water levels and yield factors of the subsoils. To obtain a closed water balance, we will need to measure deep percolation directly.

Evapotranspiration. Efforts to compute evapotranspiration rates from weather data have not proved satisfactory, primarily because of the uncertainties involved in estimating this factor under moisture stress conditions. Computations of evapotranspiration from subsequent soil moisture determinations during the monsoon resulted in unacceptably high estimates, probably due to slow internal drainage. We will try different means to improve upon the data collection on deep percolation and evapotranspiration next season.

Preliminary indications. Some indication of the relative magnitude of the water balance components may be given at this stage, taking the BW1 watershed as an example. In early July the moisture content of the 180-cm deep profile was 560-mm (Figure 45). By early November, at the end of the monsoon crop season, the moisture content of the profile had increased to about 800-mm. The rainfall from early July to early November can be estimated at approximately 650-mm. Assuming that deep percolation and runoff in watershed BW1 amounted to 140-mm (Table 36), the total evapotranspiration during the monsoon season would amount to 650–140—(800–560) = 270-mm. Evapotranspiration during the monsoon probably took place at near potential rates during much of the season because of favorable soil moisture conditions. Therefore, the estimate appears low. Errors in the computed evapotranspiration would be primarily due to the evaluation of deep percolation. Either the yield factor of the subsoils has been overestimated or water table fluctuations in the black soil watershed area may occur as a result of external events.

The effective rainfall during the rabi season was negligible. The moisture content of the 180-cm profile at the end of the post-monsoon season (March) was about 525-mm. Therefore, the evapotranspiration during the rabi season, assuming no contributions from the subsoils deeper than 180-cms., can be estimated at 800–525 = 275-mm.

Rainfall use efficiency. The total precipitation in the 1973–74 season was about 740-mm. The cropping pattern of sorghum or pearl millet in kharif followed by safflower in rabi used at least 545-mm. Although the moisture present in the profile decreased by about 40-mm between July and March, this factor is compensated by approximately 40-mm of effective rainfall which had occurred before the date of the first soil moisture determination in July. Thus the rainfall use efficiency on watershed BW1 appears to have been about 70% (545 ÷ 740 x 100). This figure, although only a first approximation, is considerably higher than the percentage of total annual rainfall used for evapotranspiration in more traditional systems of farming. A similar calculation for rabi cropping simulated on the BW4 watershed results in an estimated rainfall use efficiency of less than 50%.

FUTURE HYDROLOGIC STUDIES

It is apparent from this discussion, that substantial scope exists for improvement in studies aimed at optimum water utilization. In the coming season, we will give primary attention to improved data collection on evapotranspiration and groundwater. Additional efforts will be made to gain more accurate data on other components of the hydrologic cycle.

Red soil watersheds. The need for information of the hydrologic response under different management systems is as urgent for red soils as it is for black soils. We have started development of three natural watersheds available on the red soils at ICRISAT. Parts of the red soil watersheds are located outside of the ICRISAT boundaries which will give an opportunity to monitor hydrologic behavior of land under various management systems including over-grazed areas and one portion of a watershed occupied by a village.

The watershed-based research program. The watershed-based research program, like all programs at ICRISAT, is in its early stages of development. We feel the program has the potential of answering key questions about the optimal use of basic resources in the semi-arid tropics. Additionally, the watersheds will be the focal point where new technology and innovations from ICRISAT and other programs will meet and be tested and demonstrated on a field scale. The result we hope to achieve is integrated, productive and stable farming systems which will improve the quality of life for the people of the semi-arid tropics.

ERRATA

Page	Column	Para	Line	Correction
8	1	1	2&3	Thirty (30) year averages are an average
8	1	Table 1		of the Hyderabad and Sangareddi
8	2	Figure 1		weather stations.
10	1	4	2	"grain" should read "gram."
10	1	4	8	"*(Ascochyta rolfsi* and *Sclerotium Sclerotiorum)*" should read "*(Ascochyta rabiei* and *Sclerotium rolfsii).*"
10	2	6	4	Add "Snyder and Hanson" after "(Butler)."
22	2	2	15	"*Dolycorsis*" should read "*Dolycoris*."
23	2	3	5	"(Kuhu)" should read "(Kuhn)."
23	2	3	9	"Grain smut, (Link)" should read "Grain smut, *Sphacelotheca sorghi* (Link) Clint."
23	2	3	10	"Leaf blight, (Pass)" should read "Leaf blight, *Helminthosporium turcicum* Pass."
23	2	3	11	"Rust, (Puccinia)" should read "Rust, (*Puccinia purpurea* Cooke)."
28	1	2	3	Delete "of Ireland."
29	1	6	2	"(Walter)" should read "(Waller)."
37	2	1	7	"Sharda" should read "ICRISAT IGP."
39	1	2	2	Add "Snyder and Hanson" after "(Butler)."
39	1	3& 4		"New stem rot" and "New stem rot of Arhar" should have been acknowledged as the same disease.
47		Table 18		Under "Fodder-Fodder-Grain" in third line, "15.3" should read "151.3."
49	1	4	4	Add "in red and black soils." after "Kharif"
56		Figure 21		Caption should read "Growth response to nitrogen application on black soils is shown on sorghum, pearl millet, sunflower and maize."
67		Figure 30		On vertical axis, second number from top, "53" should read "51."

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Published by:	*International Crops Research Institute for the Semi-Arid Tropics*
Printing:	*Thomson Press (India) Ltd.*